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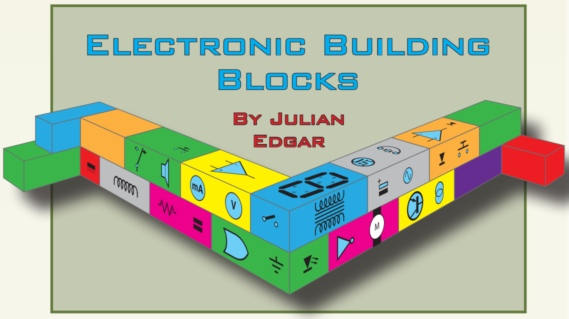

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Our December 2015 issue will be published on Thursday 5 November 2015, see page 80 for details.


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EVERYDAY PRACTICAL ELECTRONICS

Back to the thermionic future

Well, it's been a long time coming, but here at last is a really good valve project for audiophiles to sink their teeth into. Ever since I became editor, requests for projects have come in at a steady pace, and rarely has a year passed without a good handful of pleas for valve-based amplification. Unfortunately, providing a good valve amp project is not that easy – first, you need a reliable source of valves and specialist transformers; and second, you need a good, *safe* design that is relatively easy to build and handles the high voltages involved in a responsible manner.

Well, our *Silicon Chip* friends from Down Under have excelled themselves with their 'Currawong' stereo amplifier (it's an Australian songbird; and yes, I had to Google that!). It's a very nice design that manages to marry the best of contemporary technology and construction methods with traditional amplification components – thermionic valves. The use of a PCB to avoid old-fashioned point-to-point wiring is a very nice touch and… well, I won't repeat the article here – just have a read of the first part in this issue to get a feel for this excellent project.

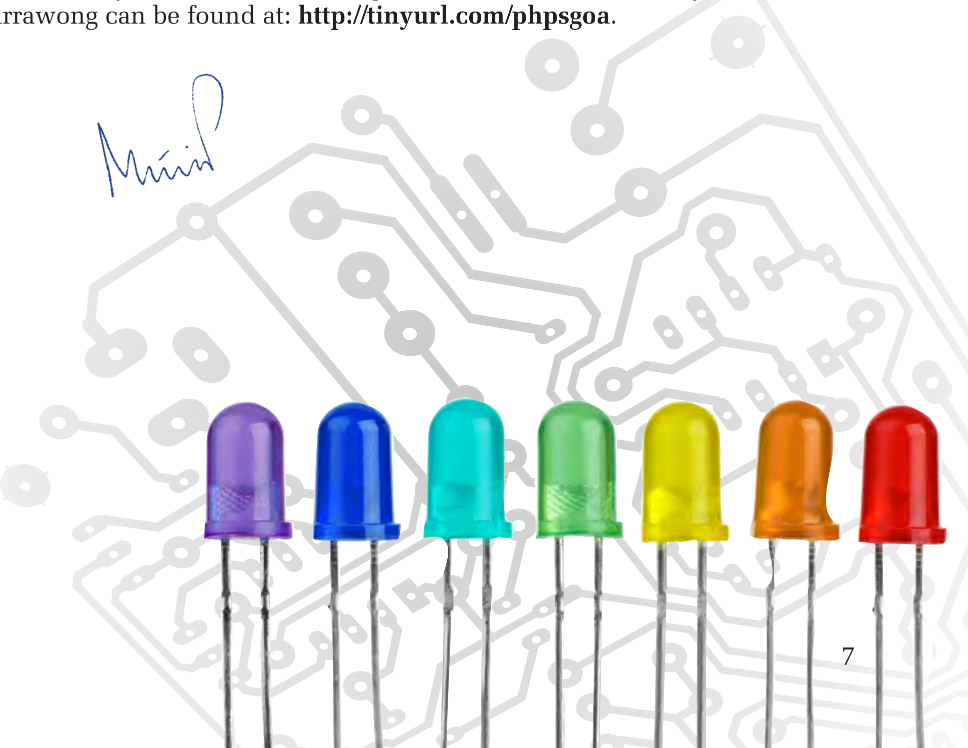
Sourcing parts

This brings me to the second issue around valve amplifiers – sourcing the parts. I'm pleased (and very relieved) to say that a full kit is available from **altronics.com.au**, which is almost certainly the most reliable way to assemble the necessary components. Delivery from Australia adds roughly 20% to the cost, which is not trivial, but nor, I hope, is it a deal breaker. Here in the UK, *Tandy* will be stocking some of the parts, including the valves (**www.tandyonline.co.uk**). If any readers find good sources of parts then do please share your discoveries on our *Chat Zone* forum.

This is a great project and I hope many are built, but please do remember it is not for novices – the voltages involved are high and you need to be careful in its construction and testing.

Songbird

For those of you with an ornithological streak, the rather lovely sound of a Currawong can be found at: **http://tinyurl.com/phpsgoa**.



NEWS

A roundup of the latest Everyday News from the world of electronics

New gadget highlights – *report by Barry Fox*

Buried among the overkill deluge of new devices and software continually being launched, a few products stand out from the noise – but sadly often spoiled because the designers can never have done the simple thing of watching how a first-time user copes with out-of-the-box setup.

Test in sunlight

Fitness wristwatch wearables are all the rage. They connect to a smartphone by Bluetooth, and log walking steps and sleep patterns, as well as telling the time. Do, however, try in sunlight before buying. I recently strapped on the Huawei TalkBand B2, which costs around £150. It's undeniably clever and stylish, but in anything halfway to bright light the display is completely unreadable. It reminds of all those digital cameras that have no direct viewfinder, just an LCD screen that flattens the battery and is useless in bright light.

Home camera

CCTV home security is a continuing growth area. Wired cameras, which show on a screen who is at the door, are old hat. Wireless cameras are taking over because they can be connected to a home network, or to the Internet to give a sight of home from across town or across the world, on a computer, tablet or smartphone.

Huawei's stylish Talkband B2 – clever, but unreadable under bright sunlight

Last year, I tried the Y-Cam Cube HD camera, costing around £250. Small, white and neat, with an SD slot for local storage, the camera connects by Wi-Fi to a home network. But it is not weatherproof, so can only be used indoors. Y-Cam Cubes also need a low voltage power supply, so they remain in effect wired cameras, which limits positioning.

Also, the setup routine is a daunting obstacle course and the instructions that came with the camera were impenetrably bad. To get it to work, and remember how I had got it working, I wrote my own instructions and sent a copy to the makers who said they were grateful. But I've heard nothing further, so I've no idea whether customers now get something more useful with their cameras.

Netgear's Arlo

The new Netgear Arlo system (at around the same price for two cameras) is far more practical. The neat little cameras are weatherproof and self-powered, with built-in batteries. The cameras have magnetic swivel mounts so they can easily be moved round a house, driveway or garden. They connect wirelessly to an indoor base station which then connects by Ethernet cable to a home network, and from there to the Internet for local or remote monitoring of the camera view.

Netgear's new Arlo system comes with two cameras that are weatherproof and self-powered, with built-in batteries, and a wireless indoor base station

The cameras have no internal storage (and no audio) but can be set to sense motion and record what they see to a cloud store, while optionally sending an email alert to the owner. All this is set up and controlled by a secure web page. The proprietary base station is needed to reduce Wi-Fi power drain, so the camera batteries should last six months.

Setup is relatively easy. I found a few practical problems; eg, camera control worked better with a Chrome browser than Internet Explorer, and it takes some trial and error to get just enough but not too many email alerts. Netgear has been very helpful and diligent in finding fixes.

I'd certainly recommend Arlo to anyone wanting to build their own security or surveillance system; I've been using it to watch wild bird feeders.

NAS home networking

Next, home networking, which is also big business, often implemented with an NAS (Network Attached

New gadget highlights – *continued*

Storage device) storing music and movies and 'serving' them to 'client' players round the home or round the world. Dutch company DVB-Logic (one of the many spinoffs from Philips) has developed TVButler – a digital TV dongle that plugs into an NAS and turns it into a TV receiver/recorder/player. It's a clever idea, but so far let down by poor instructions. A month after the company website went live, essential Get Started Help links were still broken.

Also, be warned that not all NAS devices have sufficient processing power to work with TVButler; so some are not supported.

Windows 10

Microsoft made Windows 8 (and the 8.1 upgrade) so unnecessarily different from previous Windows XP and 7, that it quickly became hugely unpopular, and deterred people from buying new PCs. So Microsoft is now giving away free upgrades to Windows 10, and thrusting the offer at existing Windows users.

Although anything would be better than Windows 8, there are several practical pitfalls to upgrading and more emerging every day. I'll give a full rundown next month. Suffice to say, for now, don't rush into upgrading an existing Windows PC to 10.

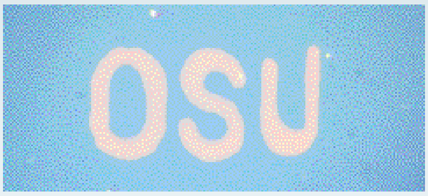
Lighting the future with quantum dots

Advances discovered at Oregon State University in manufacturing technology for 'quantum dots' may soon lead to a new generation of LED lighting that produces a more user-friendly white light, while using less-toxic materials and low-cost manufacturing processes that take advantage of simple microwave heating.

The cost, environmental, and performance improvements could finally produce solid-state lighting systems that consumers really like and help cut lighting bills almost in half, researchers say, compared to the cost of incandescent and fluorescent lighting.

The same technology may also be widely incorporated into improved lighting displays, computer screens, smart phones, televisions and other systems.

A key to the advances, which have been published in the *Journal of Nanoparticle Research*, is use of both a 'continuous flow' chemical reactor,

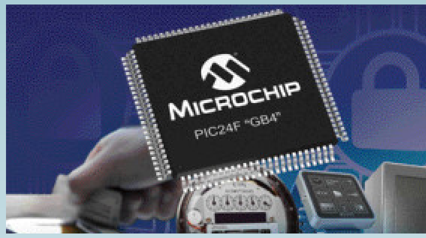


The orange color in the letters 'OSU' is produced from quantum dots viewed under a microscope, as they absorb blue light and emit the light as orange

and microwave heating technology that's conceptually similar to the ovens that are part of almost every modern kitchen.

The continuous flow system is fast, cheap, energy efficient and will cut manufacturing costs. And the microwave heating technology will address a problem that so far has held back wider use of these systems, which is precise control of heat needed during the process. The microwave approach will translate into development of nanoparticles that are exactly the right size, shape and composition.

Microchip adds security



Microchip has announced its new PIC24F GB4 family of low-power microcontrollers. Features include an integrated hardware crypto engine for secure key storage, up to 256KB of Flash memory and a direct drive for segmented LCD displays. A random number generator is used for generating random keys for data encryption, decryption and authentication, enabling a higher level of security. Its advanced features make the GB4 family ideal for designers of portable applications that require secure data transfer and storage, and a long battery life. For more information, visit Microchip's website at: **www.microchip.com**

Sinclair's new child coding scheme

A new interactive educational initiative called 'Every Child Can Code' has been announced for teaching children to code computers, catering for children from age seven or even younger. Sir Clive Sinclair's team at Retro Computers Ltd, which recently launched the ZX Vega games console, plans to encourage and enable children to code their own games programs. The children can then exchange their games with each other via email, and the company will put the best games submitted to it on the website **www.EveryChildCanCode.org** for everyone to enjoy.

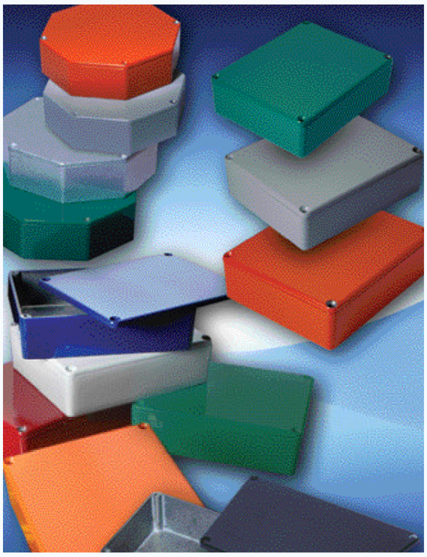
New Hammond 'stomp' boxes

Hammond Electronics' newly launched 1590 stomp die-cast aluminium enclosures are designed to accept the most commonly used switches for stomp-box applications. 'Stomp boxes', also known as guitar effect pedals, are, as the name suggests, foot-operated equipment used by electric guitarists to produce preset effects such as distortion, wah-wah, delay, chorus and phaser. Many players will have a bank of up to 20 stomp boxes, each providing a different effect.

The 1590 stomp boxes are available in rectangular, trapezoidal and octagonal designs. All are rugged, easy-to-machine enclosures, able to cope with the demanding on-stage environment in which they will be used. They are finished in a smooth gloss polyester powder paint, which does not chip after machining and provides a good surface for labels and silk screening.

A lap joint seals the units to IP54, protecting against the ingress of dust and water, and if required, the rectangular versions can have enhanced IP65 protection through the addition of an optional sealing gasket kit.

For further details on the stomp range, visit: **www.hammondmfg.com**



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TechnoTalk

Copper mountains and zinc whiskers

Mark Nelson

There's a metallic ring to this month's column, in which Mark Nelson encounters a hidden copper mountain that's right under your nose and some wayward whiskers that can destroy electronic equipment.

HAVE YOU EVER CONTEMPLATED what the least-reliable element in modern electronics might be? Think about it. I'll return to this subject at the end of this article and you can check if you were right.

Urban this, urban that!

If you follow techie jargon, you're probably familiar with the term 'urban canyon'. It's defined as a place where a city street is flanked by tall buildings on both sides, creating a canyon-like environment. Urban canyons are classic 'not-spots', where mobile phones and GPS devices struggle to find a signal. A classic urban canyon is central London's Farringdon Road, where the 'next stop' announcements that you hear aboard buses go haywire and allege you are approaching a location that's in fact several miles away.

But urban canyons are old hat now; the new thing is 'urban mining', exploiting the dormant 'copper mountains' buried beneath streets and inside offices, colleges, hospitals and industrial premises. It may sound crazy but it's not.

Copper calamity

For many in-building communications purposes, copper is still preferable to (and more economical than) optical fibre. But the amount of virgin copper remaining to be taken from the earth is finite. Typically, it takes a tonne or ore to produce one kilo of pure copper, leaving 999 kilos of rock to be disposed of. What's more, all the 'low-hanging fruit' of 'quick win' copper ore has now been extracted, meaning the remaining reserves are less concentrated, pushing up the price (and environmental fall-out) of making new copper cable. It's a highly unwelcome prospect, one that makes urban mining in dear old Britain (or whichever country you live in) look highly attractive. So what exactly is urban mining?

A fascinating article in trade magazine *Network Communications News* spilled the beans. As Kennedy Miller of cable manufacturer Brand-Rex explained, new in-building cabling systems were generally laid alongside older ones, without removing and recovering the redundant wires. This means there are literally millions of tonnes of copper lying unused in cableways all over the world. Factor in redundant telecomms and power cables, and you can see a massive and highly valuable resource that could be far easier to remove, recover and recycle. And as Miller says, recycled copper has a CO_2 factor 40 per cent lower than virgin material.

A proof-of-concept exercise at two disused data centres indicated that 91 per cent of the power and comms cables recovered were converted back to saleable copper, with nothing sent to landfill. Recycling copper involves no loss of quality, making the case for mining urban copper a no-brainer – and the decent thing to do.

Worrisome whiskers

Whisker-like growths of metallic crystals of tin and zinc were first discovered in the 1940s. At first, they were treated largely as curiosities – but disaster soon stuck. In the January 2008 issue of this magazine I mentioned the train of destruction caused by 'tin whiskers', tiny strands of tin measuring typically less than a millimetre long erupting from tin-based materials such as solder. An Associated Press report stated they were causing havoc with consumer gadgets, heart pacemakers and even a crucial part of a space shuttle. And back in the 1950s and 60s these whiskers were a primary reason causing electrical shorts that led to the failure of diodes and transistors made from germanium.

Whiskers are back in the news again, up to their old tricks, but in a different fashion. This time, the whiskers are tiny filaments of zinc (not tin) that occur on the surface of all kinds of galvanised items, including industrial cable trays and the so-called computer flooring made of wooden floor tiles with a zinc-plated steel upper surface. These are not found in a home environment, garage, den or personal workshop but are commonplace in commercial buildings.

Conductive, thus destructive

Tim Brown of British cable management company Unitrunk explains: 'Zinc whiskers grow from galvanised (electroplated) metal surfaces at a rate of up to 1mm a year. Even the slightest touch can dislodge zinc whiskers, which creates the opportunity for them then to be drawn into computer equipment. Once inside the equipment, the zinc whiskers – which are of course conductive and can carry tens of milliamps before melting – can settle onto exposed circuit boards, where they can and do, cause short circuits. Symptoms of zinc-whisker-related failures range from minor data corruption or anomalies to catastrophic hardware failures. Equipment malfunctions can be ongoing and intermittent, which makes diagnosis difficult.'

Fortunately there is a solution, but it comes at a cost. The way to go is to eliminate galvanised products altogether and opt for stainless steel. As Tim Brown sums up, this will not be the most popular solution commercially and in these difficult times even more so. However, if selected as the solution, you can be sure of no more close shaves with zinc whiskers!

Weakest point

Well, did you guess the prime weakness in electronic apparatus? A recent survey of system failure in business IT installations pointed the finger at unreliable power supply equipment. We're talking about industrial systems here, but the most common failure mechanisms are likely to apply in other branches of electronic apparatus. According to the British data centre company Timico, the most common causes of IT outages in the UK are a result of unreliable power supplies – followed by software and hardware failures. Alongside these, other common causes were human error, natural disaster and even malicious activity.

Judging by recent problems involving mobile phone and fibre broadband power supplies exploding and catching fire, you might think that switch-mode PSUs are not yet a mature technology. Of course, that cannot be the case, so I can only conclude that the shortcomings are due to quality control issues... or else with bean counters, who procure the cheapest and nastiest components and PSUs on the market. *Caveat emptor* – let the buyer beware!

The Currawong

2 x 10W Stereo Valve Amplifier –

The *Currawong* amplifier is a tried-and-tested valve amplifier circuit which has been adapted to components which are readily available. Each channel uses two 12AX7 twin triodes for the preamp and phase splitter stages, and two 6L6 beam power tetrodes in the class-AB ultra-linear output stage. It performs very well, with low distortion and noise.

This progress view of the amplifier shows it sitting in its timber plinth but without the protective perspex covers in place to protect the PCB and protect the user from high voltages.

By Nicholas Vinen

- Part 1

- 10W per channel
- Low distortion
- Good performance
- Easy to build

IN DESIGNING this amplifier, we wanted to present a unit which is straightforward to build and which has a good appearance. To satisfy the first requirement, most of the circuitry, with the exception of the power transformers, is mounted on a large double-sided PCB. Hence there is no need for point-to-point wiring from valve sockets, tag-strips, tag-boards or any of that stuff from 60 years ago.

Using the large PCB also means that we have avoided the need for an expensive metal chassis. Instead, the PCB slides into a timber plinth stained as rosewood (although you can have any timber finish you desire). As a nice finishing touch, most of the PCB will be covered and protected by a perspex cover. This will prevent little fingers from touching any part of the circuit and remove any risk of electric shock which would otherwise be possible. We hope you will like the appearance.

There are two toroidal power transformers used to power the *Currawong,* and these are concealed underneath the PCB, towards the back of the unit.

Control panel

At the front of the timber plinth, there is a small control panel suspended below the main PCB. This carries the volume control, the on/off switch, a bi-colour red/green LED, a blue LED and the headphone socket. And while it might seem like a waste to use the *Currawong Stereo Valve Amplifier* to drive headphones, we know from long experience that readers will definitely want this feature.

By the way, the red/green LED comes into play when you first turn the amplifier on. There is an initial delay while the valves heat up and during this time, no HT (high tension or high voltage) is applied to the plates of the valves which could otherwise suffer damage in the long term. So, during this delay, the LED is red. Then, when the HT is applied, the LED changes colour to green, indicating that normal operation is possible.

The other LED is lit when the headphones are in use. Plugging into the headphone socket enables a relay which disconnects the loudspeakers and connects the headphones via 220Ω resistors.

At the rear of the timber plinth is another panel which accommodates the RCA input sockets, the binding post terminals for the loudspeakers and a fused IEC socket for the mains cord. Both the front and rear panels are made from PCB material to provide a high-quality finish.

The overall performance is summarised in an accompanying panel and three graphs. It gives very good performance for a valve amplifier.

Circuit concept

A major difficulty in the design of the *Currawong* has involved the output transformers. As valve aficionados will be aware, the output transformer is usually the most expensive component in the circuit, apart from the valves themselves. Similarly, these days the power transformer is also very expensive, simply because there is no locally available off-the-shelf unit which can be pressed into service.

Yes, you can purchase imported power and output transformers, but if we had specified these, the total cost of the amplifier would have been a great deal higher. Instead, we have taken a very unusual approach in selecting the output transformer by employing a standard off-the-shelf 15W line transformer (Altronics M1115) which would normally be employed with a professional solid-state PA amplifier to drive 100V lines.

As a line driver, the transformer's primary winding is driven by a solid-state amplifier and it steps up the voltage in its multi-tapped secondary winding. In the *Currawong* though, we drive the transformers back to front, with the push-pull valve output stages driving the 100V windings and the primary windings becoming the low-impedance drive for the loudspeakers. Conveniently, the 100V winding has a centre-tap, which is necessary for push-pull operation. In addition, we use some of the other taps for the 'ultra-linear' connection.

Make no mistake though; while these are low-cost, mass-produced transformers, they have grain-oriented steel cores, a wide frequency response and low harmonic distortion. Better still, the taps on the primary winding enable it to be connected for ultra-linear push-pull operation. On the other hand, selection of this transformer is one of the two limiting factors in the maximum output power of the *Currawong*, at close to 10W per channel.

The other factor is the power transformer selection. We would have liked to use a transformer with much higher

Features and Specifications

- **Channels: 2 (stereo)**
- **Valve line-up: 4 × 12AX7 twin triodes, 4 × 6L6 beam power tetrodes**
- **HT supply: ~310V, actively filtered**
- **Tested load impedances: 4Ω, 6Ω, 8Ω**
- **Output power: 2 × 10W (8Ω, 6Ω), 2 × 9W (4Ω) (see Fig.3)**
- **Operating mode: Class-A (8Ω), Class-A/AB (6Ω, 4Ω)**
- **Input sensitivity: ~1V RMS (8Ω, with feedback enabled)**
- **Signal-to-noise ratio: 77dB**
- **Channel separation: >60dB, 20Hz-20kHz (4Ω, 6Ω and 8Ω)**
- **Harmonic distortion: typically <0.1%, 6Ω and 8Ω (see Figs.3 and 4)**
- **Frequency response: ±0.6dB, 30Hz-20kHz (see Fig.5)**
- **Damping factor: >20 (8Ω), >10 (4Ω)**
- **Mains power draw: typically 120-130W**
- **Other features: ultra-linear outputs, remote volume control option, delayed HT, HT soft-start**
- **Dimensions: 294 × 304 × 186mm (W × D × H) including protrusions**

secondary voltages but a specially-designed power transformer would be much larger and more expensive, as already noted. Having said that, there is future potential for this amplifier to be upgraded with better (more expensive) transformers to enable it to deliver substantially more output power.

The valves can be replaced without any disassembly. Their sockets are mechanically mounted to the thick (2mm) PCB to prevent the solder joints from breaking loose during valve removal or insertion. The thick PCB also helps to support the relatively high weight of the output transformers, which are mounted on the board for ease of construction.

Temperature-sensitive components such as electrolytic capacitors have been kept away from the high-dissipation components, primarily the 6L6 valves and associated 5W cathode resistors. However, due to the compact size we have not been 100% successful; one of the large filter capacitors is near the output valves. Checks of its temperature during extended operation show that direct heat transfer is minimal and should not be a problem.

Semiconductors

There are some semiconductor components in this circuit, but not in the audio signal path. Mostly, these perform power supply filtering, to get rid of ripple and keep the amplifier quiet. The HT delay and soft-start circuit is also built using solid-state components.

We should acknowledge considerable input to the design of this amplifier from Allan Linton-Smith. Allan built the first hard-wired prototype and the concept was then considerably refined and transferred to the final PCB featured in these pages. Allan also suggested using the Altronics line transformers, based on a discovery by Grant Wills that they could be used as cheap and effective ultra-linear valve output transformers – see **http://home.alphalink.com.au/~cambie/6AN8amp/Grant_Wills_6CM5amp.htm**

Circuit description

Fig.1 only shows the circuit for the left channel signal path. The right channel is identical and the corresponding component numbers are provided in blue.

The line-level input signal from RCA socket CON1 has a 1MΩ DC bias resistor to ground, in case the signal source is floating. The signal then passes through an RF-rejecting low-pass filter comprising a 120Ω series resistor and 100pF ceramic capacitor.

The signal is then AC-coupled to VR1, a (nominally) 20kΩ logarithmic volume-control potentiometer, by a 1.5µF MKT capacitor. This gives a –3dB low-end roll-off at 5Hz. Note that depending on part availability, a motorised potentiometer with a value as low as 5kΩ may be used, in which case the –3dB point rises to 21Hz.

The wiper terminal of VR1 is connected to ground via a 1MΩ resistor so that if it briefly goes open circuit during volume changes, the grid of V1a does not float. The signal is fed to this grid via a 22kΩ RF stopper resistor.

V1a and V1b form the preamplifier. Essentially, this consists of two common-cathode amplifier stages in series, with negative feedback around both.

V1's plates are fed from a filtered HT rail of around 224V DC, somewhat less than the 308V DC main HT rail due to voltage drops across the two RC filter resistors (6.8kΩ and 47kΩ). These filters reduce coupling between channels, reduce coupling from the output stage to the preamp stages and minimise supply ripple reaching the preamp. The preamp is the most noise-sensitive section as the signal level is lowest here.

In fact, because hum can be picked up from AC-powered heater filaments, we are running the 12AX7 filaments from regulated 12V DC.

Self biasing

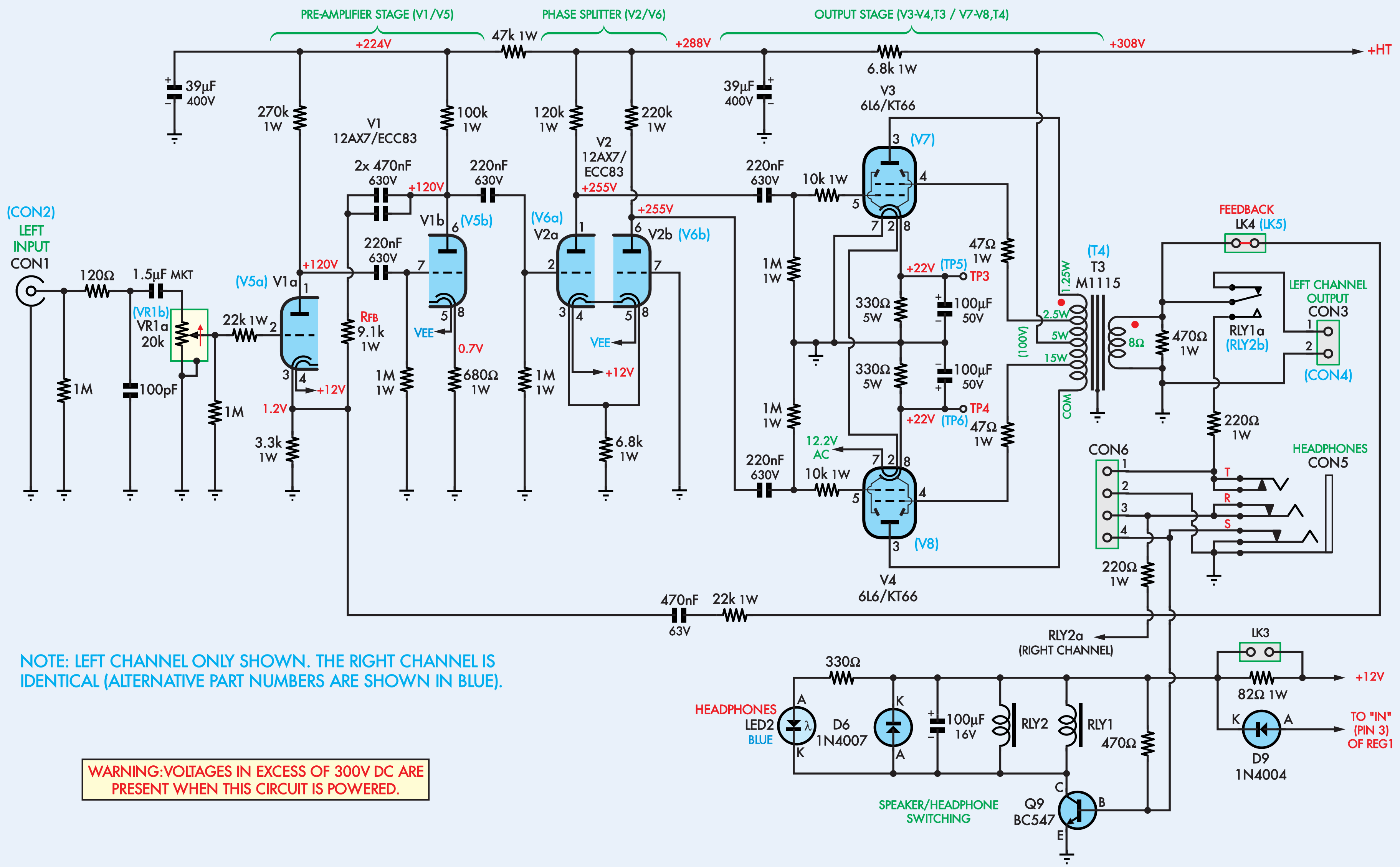
All valves in the circuit are self-biased. V1a's anode runs at around 120V, ie, 224V minus the drop across the 270kΩ resistor. With zero bias, a 12AX7 will conduct around 3mA at this voltage, dropping to near-zero with a grid-cathode bias of around –2.2V. With a 3.3kΩ cathode resistor, V1a's operating point tends to settle at about 0.3mA and thus the cathode is 1.2V above ground.

The output signal from V1a's anode is coupled to V1b's grid by a 220nF capacitor and this grid is DC biased using a 1MΩ resistor to ground. V1b runs at a higher power than V1a, with a 680Ω cathode resistor giving an operating current of around 1mA. Therefore, its anode load resistance is lower at 100kΩ.

The output at V1b's plate is coupled back to V1a's cathode via a pair of parallel 470nF polyester capacitors (ie, around 1µF) in series with a 9.1kΩ resistor. This sets the closed-loop gain of the preamp section at around 2.75, so that the following phase splitter receives around 3V RMS at maximum volume. Note, however, that there is also a feedback path from the amplifier's output, which we will cover later.

Phase splitter

The phase splitter is another 12AX7 twin triode, V2. The phase splitter



CURRAWONG STEREO VALVE AMPLIFIER
(AMPLIFIER SECTION)

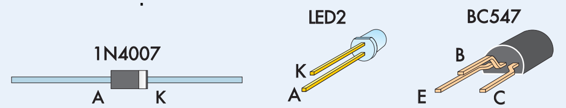
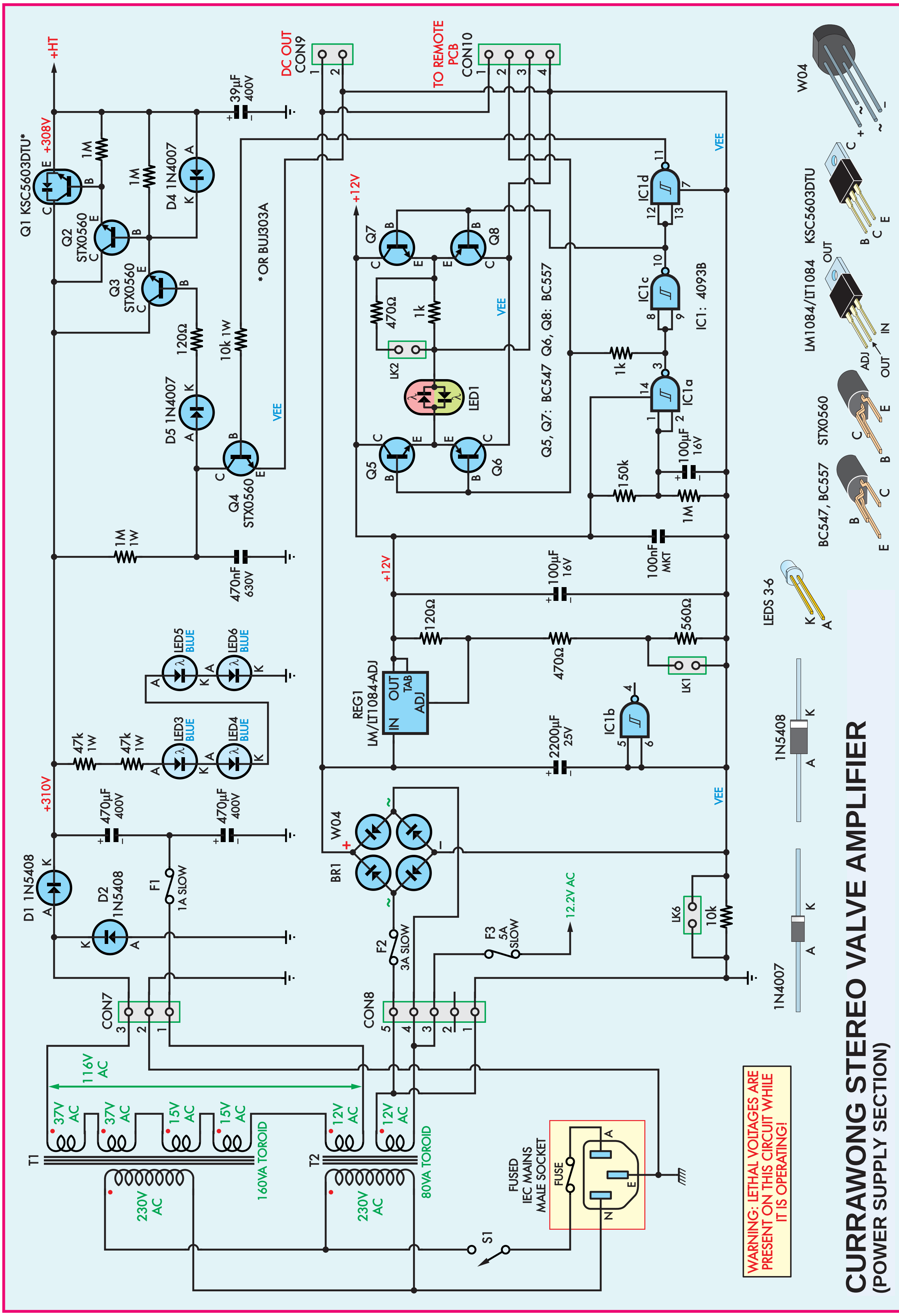


Fig.1: the left channel circuit of the *Currawong Stereo Valve Amplifier* (the right channel is identical). The incoming signal passes through a low-pass RC filter and volume pot VR1 and is then fed into V1 (a 12AX7 twin triode) which provides signal preamplification in two stages. Its output is then fed to V2 (another 12AX7 twin triode) which operates as a phase splitter and gain stage to drive push-pull output pair V3 and V4 (both 6L6 or KT66 tetrodes). Output transformer T3 has tapped connections to the output valve screens for ultra-linear operation. The transformer output is switched to either the speaker terminals (via CON3) or to the headphone socket by relay RLY1.



CURRAWONG STEREO VALVE AMPLIFIER
(POWER SUPPLY SECTION)

Fig.2: the secondaries of toroidal power transformers T1 and T2 are connected in series and rectified using a voltage doubler to produce a 310V HT rail. Most of the ripple is filtered out by a capacitance multiplier comprising high-voltage transistors Q1-Q3 and a 470nF polyester capacitor. T2's remaining 12VAC secondary drives the 6L6 filaments directly in a series/parallel configuration, while the 12AX7 filaments run from a regulated 12V rail produced by bridge rectifier BR1, a 2200µF filter capacitor and linear regulator REG1. IC1 provides an HT turn-on delay and soft start.

provides some gain, but its main job is to produce two similar drive signals with opposite phase for the grids of the push-pull output stage valves. Signal is coupled to this phase splitter from V1b's anode via another 220nF polyester capacitor.

V2a operates as an inverter, to generate the out-of-phase drive signal. Like V1a and V1b, it is configured as a common-cathode amplifier. It runs from a higher HT rail of around 288V DC which comes from the first HT RC filter stage (6.8kΩ/39µF). Its grid is tied to ground by a 1MΩ resistor, with the voltage across the shared 6.8kΩ cathode resistor providing the required bias potential.

This resistor is shared with V2b (and both cathode currents flow through it). V2b's grid is connected straight to ground, so when its cathode voltage increases, the grid-cathode bias voltage decreases. As such, when V2a's cathode current increases and its anode voltage drops, V2b's bias increases and thus V2b's anode/cathode current decreases, causing the voltage at its anode to rise.

So, the signal at V2b's anode has the opposite phase to that at V2a's anode, ie, it is in phase with the signal from the preamp. The 220kΩ anode resistor value has been selected so that the two output signals have a similar swing and so that V2a and V2b both operate with as high an anode voltage as possible, to give maximum drive amplitude for the following stage.

These drive signals are applied to the grids of 6L6 output valves V3 and V4 via 220nF polyester capacitors. These grids are again tied to ground by 1MΩ resistors and there are 10kΩ series stopper resistors to prevent parasitic oscillation.

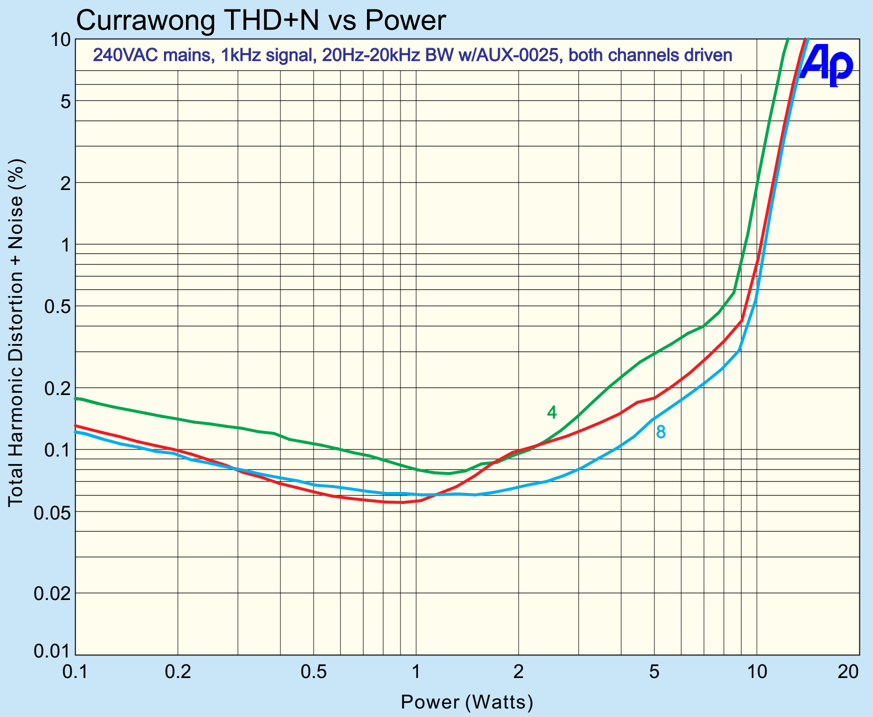


Fig.3: distortion versus power for a 1kHz sinewave into 4Ω, 6Ω and 8Ω load impedances. Again, both channels are driven for a realistic test. As you can see, distortion remains low at under 2W and then rises slowly until the onset of clipping at around 8-10W, depending on load impedance. The best power delivery is actually for 8Ω loads, with 6Ω being virtually identical and 4Ω being a little lower, clipping at around 9.5W/channel. This is partly due to output transformer drive impedance mismatch.

Output stage

V3 and V4 are self-biased using 330Ω 5W cathode resistors, with around 22V across each. This gives an operating current of about 65mA. Each output valve is powered from the main HT rail of around 308V, via the primary windings of T3, for a quiescent power of around 20W each.

Note that DC and AC currents flow in the two halves of the push-pull winding since both plates of the tetrodes are fed from the transformer centre-tap connection. However, the magnetic fields produced by these direct currents are cancelled, as they flow in opposite directions. This is important, because otherwise the transformer would be magnetically saturated.

As the current split between V3 and V4 changes in response to the input signal however, an AC magnetic field is induced which is coupled into T3's secondary. The resultant voltage drives the speakers or headphones.

Since the output valve quiescent power of 20W is around twice the amplifier's power output of 10W per channel into 8Ω, this gives Class-A operation. With lower load impedances (for example, 4Ω), V3 or V4 may be fully cut off during signal peaks, giving Class-AB operation.

When the input signal swing is positive, pin 1 of V2a has a negative swing and so the current through V3 drops. At the same time, pin 6 of V2b has a positive swing and thus the current through V4 increases. This causes an increase in current flow from the top (dotted) side of T3's primary to the other, resulting in a positive swing at the dotted side of the secondary. Thus, the output of the amplifier is in phase with the input.

T3 also has taps approximately halfway between each end and the centre (HT) tap. These are connected to the screens of V3 and V4 via 47Ω stopper resistors, providing the ultra-linear connection mentioned earlier. This negative feedback from the transformer to V3 and V4 cancels out some of the transformer distortion. Note that while the feedback signals are high amplitude, the screen gain is much less than for signals applied to the grid, so the feedback doesn't overpower the drive signals.

Because the signal levels in the output stage are much higher and since 6L6 valves require much more filament current than 12AX7s, we run the filaments of V3 and V4 (and V7/V8) from 6.1V AC, slightly shy of the nominal 6.3V, due to compromises made in power transformer selection. It still works fine; it just takes a little longer for the valves to reach full emission after switch-on.

Speaker connections and feedback

A 470Ω 1W resistor across T3's secondary ensures that there is some load

Parts List

Chassis/power supply

1 timber plinth with base (details to come)
1 top cover cut from 3mm clear acrylic (details to come)
1 small tube acrylic glue
1 front panel, available from the *EPE PCB Service*, code 01111142, 249 × 30mm
1 rear panel, available from the *EPE PCB Service*, code 01111143, 248 × 53mm
1 160VA 37+37+15+15V toroidal transformer
1 80V A 12+12V toroidal transformer
4 screw-on 30mm equipment feet
4 M4 × 15mm machine screws and nuts (for feet)
1 15mm anodised aluminium knob to suit VR1
1 snap-in fused IEC mains male socket for 1.6mm panels
2 M205 250V AC 1A slow-blow fuses (one spare)
1 red chassis-mount RCA/RCA socket
1 white chassis-mount RCA/RCA socket
2 red RCA line plugs
2 white RCA line plugs
2 red binding posts
2 black binding posts
1 SPST ultra-mini rocker switch, 250V AC rated
1 1m length 2-core mains flex
1 1m length 3-core mains flex
1 200mm length 3mm diameter black heatshrink tubing
1 200mm length 8mm diameter black heatshrink tubing
1 200mm length 20mm diameter black heatshrink tubing
1 1m length heavy duty red hook-up wire
1 1m length heavy duty black hook-up wire
1 1m length single-core shielded cable
1 1m length medium duty black hook-up wire
1 12-way screw terminal strip
6 M3 × 25mm nylon screws and nuts
1 M4 × 6mm machine screw
2 M4 nuts
2 4mm ID shakeproof washers
1 4mm ID eyelet crimp connector
3 red 6.4mm crimp spade connectors
12 4G × 9mm self-tapping screws
10 small nylon cable ties

Main board

1 double-sided PCB, available from the *EPE PCB Service*, code 01111141, 272 × 255mm
2 15W 100V line transformers (T1,T2) (Altronics M1115 – do not substitute)
2 5V DC coil 3A contact SPDT micro relays (RLY1,RLY2)
6 M205 fuse clips (F1-F3)
1 1A M205 slow-blow fuse (F1)
1 3A M205 slow-blow fuse (F2)
1 6A M205 slow-blow fuse (F3)
1 white vertical RCA socket (CON1)
1 red vertical RCA socket (CON2)
2 2-way vertical pluggable terminal blocks (CON3,CON4)
1 PCB-mount switched 6.35mm stereo jack socket with long pins (CON5)
1 3-way vertical pluggable terminal block (CON7)
1 5-way vertical pluggable terminal block (CON8)
4 chassis-mount phenolic 9-pin valve sockets with bracket (V1,V2,V5,V6)
4 chassis-mount ceramic 8-pin valve sockets with bracket (V3,V4,V7,V8)
6 2-way pin headers, 2.54mm pitch (LK1-LK6)
2 shorting blocks (LK4-LK5)
1 5-50kΩ 16mm dual gang log pot* (VR1)
2 6073B-type mini flag heatsinks
4 M4 × 10mm machine screws
4 M4 shakeproof washers
4 M4 nuts
8 M3 × 15-16mm machine screws
10 M3 × 10mm machine screws
12 M3 shakeproof washers
12 M3 nuts
14 M3 nylon nuts
22 3mm inner diameter nylon flat washers
8 6.3mm M3 nylon tapped spacers
2 TO-220 insulating washers and bushes

The Currawong contains some hard-to-source components. A kit is available from **altronics.com.au** – code K5528, which is much the easiest way to assemble the parts. Readers who wish to buy parts individually should consider: **www.tandyonline.co.uk** for valves; **www.siliconchip.com.au/Shop/7/2877** for various items; and Altronics for the all-important specified transformers T1, T2.

even if there is no speaker connected. This is necessary because operating a push-pull transformer-coupled amplifier with no load can lead to very high AC voltages at the valve plates and subsequent flash-over in the valve sockets.

T3's secondary connects to the speaker terminals via the normally closed contacts of RLY1 and pluggable terminal block CON3.

RLY1 is energised if headphones are plugged into the front panel socket, disconnecting the speaker and redirecting the signal to headphone socket CON5 via a 220Ω resistor.

If LK4 is fitted (and we recommend that it is), feedback is applied from T3's secondary to V1a's cathode via a 470nF capacitor and 22kΩ resistor. Since the output is in phase with the input, by applying some of the output signal to V1a's cathode, we effectively reduce the drive for V1a, giving about 14dB of negative feedback.

There is a limit to how much feedback can be applied in this manner due to the phase shift created by the inductance of T3. We have set the feedback to give as much distortion cancellation as possible, while keeping it stable with capacitive loads.

The circuit as presented is stable with several microfarads across the load, even when driving it with a square wave. Note that the 470nF capacitor in the feedback path is important as it damps shifts in valve bias in response to changes in mains voltages and valve temperatures.

With feedback enabled, input sensitivity is around 1V RMS. Typical CD/

1 1m length medium duty blue hookup wire (250V ;/AC rated)

1 1m length shielded audio cable
1 200mm length 3mm diameter blue heatshrink tubing
6 small green nylon cable ties (maximum 2mm wide)
2 small blue nylon cable ties
* ≥ 20kΩ recommended; substitute motorised pot for remote control option (see details in Part 2 next month)

Valves
4 12AX7 dual triodes (V1,V2,V5,V6)
4 6L6 beam tetrodes – matched pairs if possible (V3,V4,V7,V8)
(the valves listed above are available from **www.tandyonline.co.uk**)

Semiconductors
1 4093B quad NAND Schmitt trigger IC (IC1)
1 LM/LT1084-ADJ 5A adjustable low-dropout regulator (REG1)
1 KSC5603D 800V 3A high-gain NPN transistor (Q1)
3 STX0560 600V 1A NPN high-gain transistors (Q2-Q4)
3 BC547 100mA NPN transistors (Q5,Q7,Q9)
2 BC557 100mA PNP transistors (Q6,Q8)
1 red/green 2-lead bi-colour 3mm LED with diffused lens (LED1)
5 blue diffused lens 3mm LEDs (LED2-LED6)
1 W04 1.5A bridge rectifier (BR1)
2 1N5408 3A 1000V diodes (D1,D2)
3 1N4007 1A 1000V diodes (D4-D6)
1 1N4004 silicon diode (D9)

Capacitors
1 2200µF 25V electrolytic
2 470µF 400V snap-in electrolytic
4 100µF 50V electrolytic
3 100µF 16V electrolytic
5 39µF 400V low-profile snap-in electrolytic (Nichicon LGJ2G390MELZ15) (Mouser)
2 1.5µF 63V MKT
5 470nF 630V polyester
2 470nF 63V MKT
8 220nF 630V polyester
1 100nF 63V MKT or 50V multi-layer ceramic
2 100pF ceramic disc

Resistors (1W, 5%)

9 1MΩ	2 9.1kΩ
2 270kΩ	4 6.8kΩ
2 220kΩ	2 3.3kΩ
2 120kΩ	2 680Ω
2 100kΩ	2 470Ω
6 47kΩ	2 220Ω
2 22kΩ	1 82Ω
4 10kΩ	4 47Ω
4 330Ω (5W, 10%)	

Resistors (0.25W, 1%)

7 1MΩ	1 560Ω
1 150kΩ	3 470Ω
2 10kΩ	1 330Ω
2 1kΩ	4 120Ω

Warning!

Note: parts of this circuit operate at over 300V DC. Do not touch any components or any part of the PCB while the unit is operating or immediately after switch off. The blue LEDs in the circuit indicate when dangerous voltages are present.

DVD/Blu-ray players produce around 2V RMS, so this should be plenty in most circumstances. With LK4 removed, the overall gain is much higher and the input sensitivity is around 350mV RMS for full power. However, distortion rises to around 0.5% at 1kHz and >1% at lower frequencies.

Note that the 470nF series capacitors in the feedback network are important. These form high-pass filters in combination with the feedback resistors, with a –3dB point of around 15Hz. If DC feedback is used, the bias time constants in the circuit form a type of relaxation oscillator and the bias voltages never quite settle down, leading to asymmetric clipping and other undesirable behaviour.

Power supply

The separate power supply circuit is shown in Fig.2. All components, except the two power transformers T1 and T2, power switch S1 and the fused IEC mains socket, are on the main board.

There are three main power requirements for this circuit: the 310V HT rail, the ~12V DC filament supply for the 12AX7s (at around 1A) and ~6V AC for the 6L6 filaments, at around 4A. We also use the 12V DC rail to power various ancillary circuits, as described below.

All of T1's secondaries are connected in series, along with one of T2's secondaries, to produce 114V AC. T2's other secondary provides a little over 12V AC, to run the 6L6 filaments at around 6.1V AC each, in series pairs. The 12V AC is also rectified, filtered and regulated to provide the 12V DC rail (actually about 12.3V DC), for the 12AX7 filaments and DC-powered circuitry.

The 114VAC from CON7 is rectified in a half-wave voltage doubler consisting of 1000V 3A diodes D1 and D2 and two 470µF 400V capacitors, giving about 310V across both capacitors with several volts of ripple. Fuse F1 provides some protection against faults.

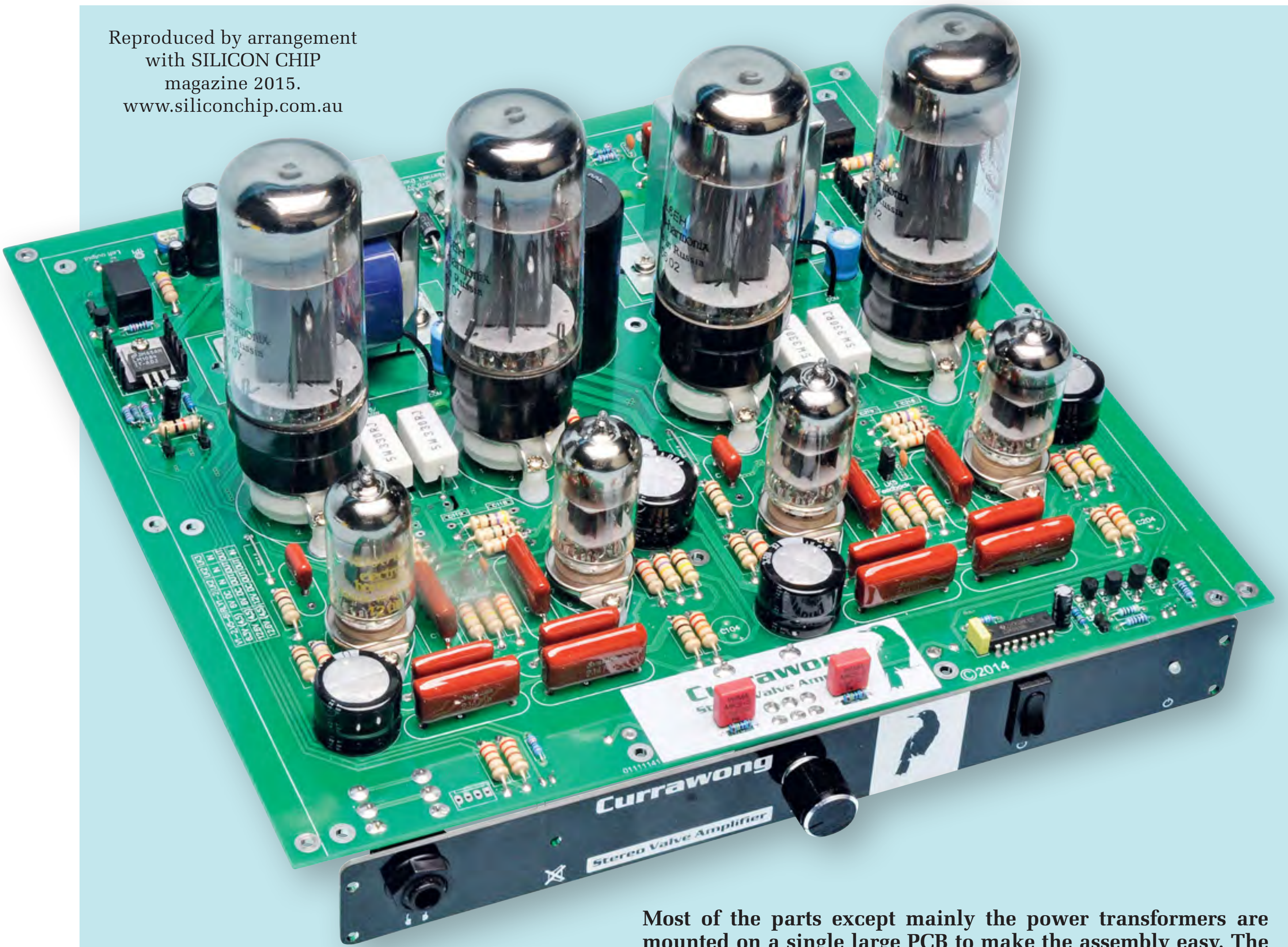
There are two 47kΩ series-connected bleeder resistors to discharge the 470µF capacitors when power is removed. Four blue LEDs are connected in series with the two 47kΩ 1W resistors. The blue LEDs indicate the presence of HT and also illuminate output transformers T3 and T4 (very effective in a room with subdued lighting).

The output stage has no HT low-pass filter, unlike the preamplifier and phase splitters. So to prevent HT ripple in the output stage from affecting the signal, we are using an active ripple filter. This is a capacitance multiplier filter built around high-voltage, high-current transistor Q1, configured as an emitter-follower.

The traditional HT filter is a large iron-cored choke, but these are heavy and expensive, not to mention hard to find these days. Our transistor-based method is more effective and cheaper.

Q1 is driven by Q2 and Q3 which are high-voltage high-gain signal transistors, in a 'Triplington' configuration; it's like a Darlington but with an extra stage. The higher the gain in this buffer, the more effective the filter. Base bias comes from an RC low-pass filter across the incoming HT rail, consisting of a 1MΩ resistor and 470nF polyester capacitor.

Q2 and Q3 have a gain of around 70-100 each, while Q1 has a gain of around 30. So the overall gain is about 70 × 70 × 30 = 147,000 which multiplies the effect of the 470nF capacitor to act as if it is 69,000µF! In practice, it



Most of the parts except mainly the power transformers are mounted on a single large PCB to make the assembly easy. The optional remote volume control is built on a separate PCB.

isn't quite as good as this as the 470nF capacitor discharges slightly through the three base-emitter junctions at the trough of each ripple cycle, but despite this, the ripple at Q1's emitter is just a few hundred millivolts.

Q1 has an integral emitter-collector diode so that when the unit is switched off, the output filter capacitors can safely discharge back into the input filter capacitors without doing any damage. D4 protects Q2, while D5 provides similar protection for Q3 but also has a role in the start-up delay, which we'll explain later.

Note that this arrangement also results in HT 'soft-start' as it takes a few hundred milliseconds for the 470nF capacitor to charge and the HT rail tracks this voltage.

Turn-on delay

We have also incorporated a 20-second (or so) turn-on delay, to allow the valve filaments to heat up before HT is applied. Part of the rationale for this is to prevent 'cathode stripping', which can occur with cold cathodes, although the existence of this phenomenon is somewhat controversial. But since the valves aren't 'ready' to operate immediately anyway, it certainly doesn't hurt to delay the application of HT.

IC1 is a quad Schmitt-input NAND gate, which runs from the 12V rail and provides the turn-on delay. Note that ground for the 12V rail is labelled V_{EE} and will be close to, but not necessarily at, GND (0V).

IC1a is connected as an inverter with a 100µF capacitor from its input to ground. A 150kΩ resistor charges this capacitor from the 12V rail, while a 1MΩ resistor discharges it when power is switched off. It takes about 20 seconds for this capacitor to charge to a sufficient voltage for the output of IC1a to go low.

During this time, IC1a's output is high. This is inverted by IC1c and then again by IC1d, so Q4 (another 600V transistor) is switched on initially. This keeps the 470nF capacitor in the HT filter from charging until the delay has ended. Diode D5 in the HT filter prevents the base of Q3 from being pulled below GND when V_{EE} is (slightly) negative.

IC1a and IC1c also drive LED1 via two pairs of complementary emitter-followers (Q5-Q8). LED1 is a bi-colour device and consists of a red LED and green LED on the same die, connected in inverse parallel. Since inverter IC1c is between them, one inverter is always driving one end of LED1 high and the other is driving it low. Thus, LED1 is red initially at turn-on and switches to green once the time-out period has expired and the HT rail is powered up.

A 1kΩ resistor sets the LED current to about 10mA, while another 1kΩ resistor partially isolates the bases of Q5

and Q6 from IC1a's output. This allows the optional remote control board to independently drive LED1, in order to flash it to acknowledge infrared command reception. The remote control board connects via CON10 and will be described next month.

Low-voltage supplies

5-pin pluggable terminal block CON8 provides separate low-voltage AC connections for the 6L6 filaments (pins 1 and 3) and the regulated supply (pins 4 and 5). Each is fused on the board. However, we ultimately decided to use one transformer winding to power both, hence they are wired in parallel despite the separate connections.

The 12V AC from pins 4 and 5 of CON8 is rectified by BR1, a 1.5A bridge rectifier and filtered with a 2200µF capacitor to produce around 15-16V DC with about 1V ripple. This is regulated to provide a nice smooth rail by REG1, a low-dropout, high-current equivalent to the LM317.

Pins 1 and 3 of CON8 connect straight to the series/parallel-connected 6L6 filaments and as a result, they get about 6.1VAC each. One end of this AC supply is grounded for noise immunity.

Now, because of this ground connection and the fact that the same transformer secondary is used to feed BR1, the negative end of BR1 actually floats between about +0.7V and –15V. Hence, the need to disconnect V_{EE} from GND. If two separate 12V transformers or windings were used, LK6 could be fitted and thus V_{EE} would be at the same potential as GND. **LK6 must not be fitted with the supply arrangement shown here!**

The circuit will work the same regardless as to whether V_{EE} is connected to GND, as Q4 is the only connection between the two supply 'domains'.

The DC supply is also used to power relays RLY1 and RLY2 when headphones are plugged in. These are 5V relays, so an 82Ω series resistor drops the 12V DC to an appropriate voltage. LED2 is also connected across the relay coils, in series with a 330Ω current-limiting resistor, to indicate when the speakers are disconnected.

Unused linking options

Note that the supply was also designed to operate with the regulated rail at 6V DC rather than 12V. This would require a different transformer (ie, 6V AC rather than 12V AC) and the option was provided as there are some 12AX7-compatible valves with 6.3V-only filaments (rather than the typical arrangement with a 12.6V centre-tapped filament).

However, given the relative rarity of these valves, we aren't going to go

The PCB is slid into a slot that runs around the top inside edge of the timber plinth. Perspex covers will be used to protect the PCB and speaker transformers.

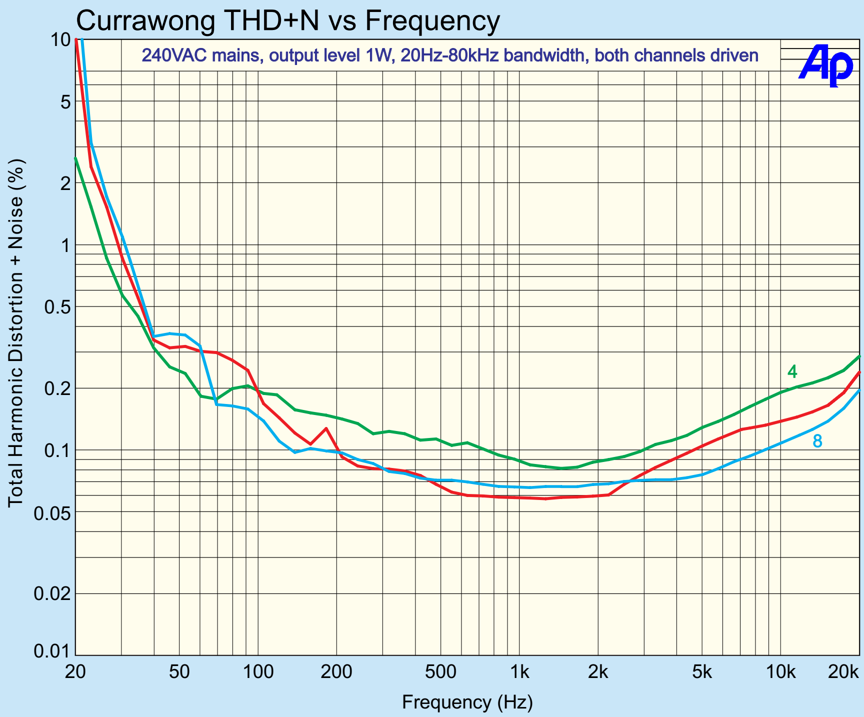


Fig.4: distortion versus frequency, with both channels driven at 1W into three different resistive loads. As you can see, the distortion is pretty low for a valve amplifier, especially between 100Hz and 10kHz. Below 100Hz, distortion rises steeply due primarily to the output transformer's non-linear response. Distortion into lower impedances is only slightly worse than that for 8Ω. Note the 80kHz bandwidth used, to ensure that higher frequency harmonics are included in the measurements.

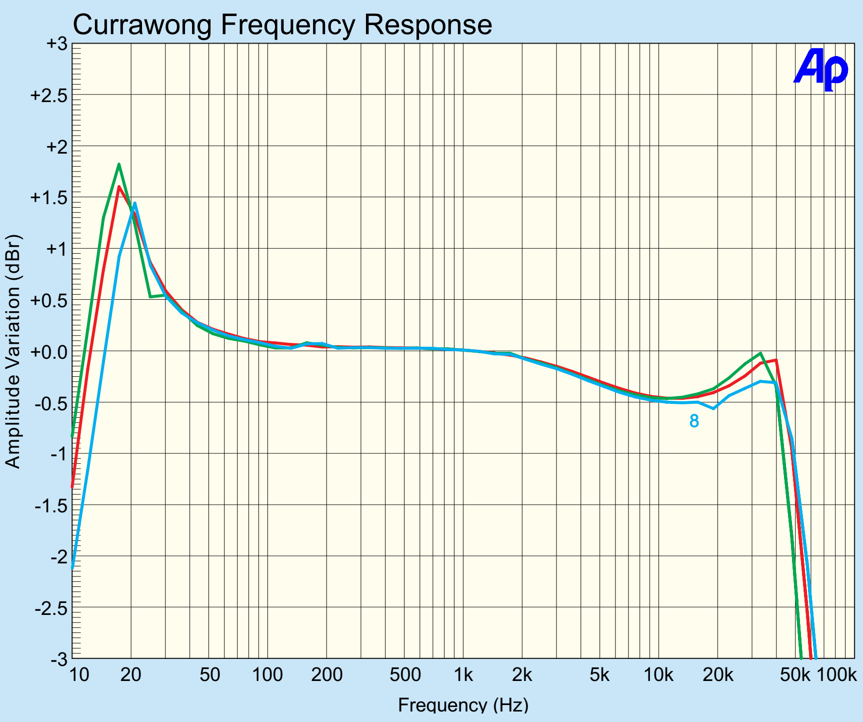


Fig.5: the frequency response is pretty flat in the audible range (note: the vertical scale is only ±3dB for the entire diagram). Roll-off at the high frequency end is –3dB at around 50kHz, while the low-end –3dB point is below 10Hz. The peak at around 20Hz is partly due to the AC-coupled global feedback and partly due to greatly increased waveform distortion below about 30Hz due to the output transformers. However, the peak amplitude is only around +1.5dB and 20Hz signals are barely audible.

into details as to how to reconfigure the supply except to say that LK1-LK3 are fitted for this purpose. Normally, they are left out.

PCB layout

We wanted to put as many parts on the PCB as possible to make this amplifier easy to build. Soldering parts to a PCB is certainly a lot easier than point-to-point wiring! It minimises the chances of mistakes and also means that performance will be consistent between amplifiers.

The PCB layout was a bit tricky though, due to the voltages involved. We have kept tracks with voltages that may differ by over 60V apart by 2.54mm to prevent arcing, while in other areas, low-voltage tracks need to be closer together so they can fit. We also used 'star' earthing as much as possible to avoid hum and ripple injection into the preamp stages. Most of the grounds on the board converge on the main power supply filter capacitor negative pin.

The board has been designed with plated slots for the valve socket pins so that they fit snugly and neatly.

All connectors have been placed along the back of the board, on the underside, to keep the chassis wiring neat. The input signals run from the back of the board to the front (where the volume pot is mounted) through shielded cables that are strapped to the underside of the board, to prevent the low-level input signals from picking up ripple, hum and buzz.

We have also used low-profile components where possible, so that a clear perspex shield can be fitted over the top, to prevent prying fingers from getting a shock, as mentioned earlier. The valves, main filter capacitors and output transformers will pass through cut-outs in this shield, with perspex boxes around the transformers. The rest of the components will be safely underneath.

Next month

That's all we have room for this month. Over the next couple of months we will present the main PCB layout diagram, describe the assembly procedure, explain how to build the plinth and finish the wiring. We'll also go through the testing and troubleshooting procedure and describe the optional infrared remote control which uses a motorised potentiometer.

Win a Microchip Motor Control Starter Kit With mTouch Sensing Demo Board

EVERYDAY PRACTICAL ELECTRONICS is offerring its readers the chance to win a Motor Control Starter Kit with mTouch Sensing Demo Board (part no DM330015). The Motor Control Starter Kit with mTouch Sensing is a complete hardware and software tool suite for evaluating Microchip's ultra-low cost Motor Control Family dsPIC DSCs. It contains a single board with a BLDC motor, capacitive-touch sliders and a built-in debugger.

The 2" × 5" demo board Motor Control Starter Kit with mTouch Sensing has a compact design and includes features such as: very low cost 16-bit Motor Control DSC (dsPIC33FJ16MC102), on-board in-circuit programming/debug via USB, an on board 3-phase BLDC motor, 15V, 2.6A on-board drive circuit with pads for user-supplied motor, capacitive touch slider for speed control with LED indicators, and it is powered via a 9V power supply.

HOW TO ENTER

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CLOSING DATE

The closing date for this offer is 30 November 2015.

By JOHN CLARKE

48V Dual Phantom Power Supply for DI boxes and Condenser Microphones

Lots of audio equipment needs phantom power. As well as condenser microphones, it's also required for active DI boxes, preamplifiers and effects units. This phantom power supply runs from a 24VAC plugpack transformer and delivers a regulated 48V DC via XLR sockets.

PUBLIC ADDRESS systems in theatres, churches and halls all require microphones, preamplifiers and possibly powered DI (direct injection) boxes and effects pedals for musicians. Many microphones are dynamic types that do not require a power source, but the more sensitive condenser microphones require power and the same goes for other items of equipment.

While these can often be run from batteries, it is far more convenient to have a 'phantom supply'. This avoids the need to check batteries that can go flat at the most inconvenient times, ie, when you need 'em!

So what's a phantom supply? Well, it's a handy way of providing power to equipment via balanced signal leads. 'Phantom' refers to the apparently invisible manner in which power is applied. 48V DC is the favoured phantom supply standard in the commercial sound industry. 24V and 12V are also used, but these are not popular.

Fig.1 shows how it's done. The 48V DC supply is applied via 6.8kΩ resistors to the hot (non-inverted) and cold (inverted) signal leads for the device being powered. The output signal leads from the unit are capacitively coupled to the following device, so that the DC voltage is removed from the signal.

Phantom supplies should not be confused with the bias voltage applied to electret microphones. A bias supply is applied to an unbalanced lead comprising a shield and signal wire, rather than to a balanced signal line with a shield. Additionally, such a bias supply is typically around 1.5V and has a current of 1mA or less. More information about this can be found at: **http://blog.shure.com/shure-notes/shure-tech-tip-phantom-power-vs-bias-voltage/**

So what happens if a phantom supply is connected to a dynamic microphone? Will it be damaged by current flow? The answer is 'no'.

Fig.2A shows this connection. A dynamic microphone employs a coil that's floating and not connected to the

grounded shield. With 48V applied to both sides of the coil, no DC current flows through it.

Problems can arise when a dynamic microphone or the connecting lead is wired incorrectly, with one side of the microphone coil connected to ground, as shown in Fig.2B. Current would then flow in the coil, leading to magnetisation that may permanently affect the microphone.

Problems also occur if a centre-tapped microphone coil is incorrectly connected to ground at the centre tap (Fig.2C). In this case, a different current may flow in each half of the coil due to slight differences in the values of the 6.8kΩ resistors and imbalances in the coil windings.

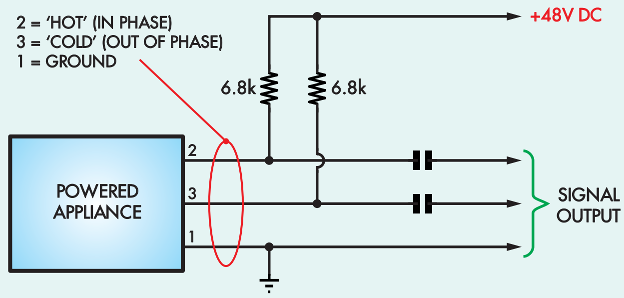
Getting back to Fig.2A, matching the 6.8kΩ resistors will also improve noise rejection due to more equal impedance matching in the two signal leads. For those unfamiliar with balanced audio leads, the twisted pair wires in the balanced lead carry out-of-phase signals. At the receiving end, the out-of-phase signals are 'subtracted' and this has the effect of 'adding' the two signals.

In addition, because they are twisted, the signal wires each tend to pick up the same level of hum and this is cancelled by the subtraction at the receiving end. A shield wire that's connected to ground further minimises hum and noise pick-up.

Some mixing desks do include a phantom supply for microphones. However, even if you do have such a mixing desk, it may not have sufficient capacity. This new 48V Dual Phantom Power Supply can be used with two phantom-powered devices.

As shown in the photos, the *48V Dual Phantom Power Supply* is housed in a diecast box, for ruggedness and for shielding. It has two female XLR sockets and two male XLR sockets. The 48V supply is applied to the female XLR sockets, while the male sockets provide the signal output with the DC voltage blocked by 22µF electrolytic capacitors.

Fig.1: how phantom power is applied. The 48V DC supply is applied via 6.8kΩ resistors to the balanced signal leads of the device being powered.



Circuit details

Now take a look at Fig.3 for the full circuit details. As shown, the incoming 24VAC from the plugpack transformer is connected to a half-wave voltage doubler rectifier, comprising diodes D1 and D2 and two 470µF 63V electrolytic capacitors. This will result in a nominal DC voltage of about 67V, but will typically be much higher at around 75V DC, depending on the incoming mains voltage and the plugpack's voltage regulation.

REG1, an LM317 3-terminal adjustable regulator, is used to derive the 48V DC supply. This device is rated for a maximum differential of 40V between its input and output. With a 75V input and a 48V output, the input to output difference is a comfortable 27V, but when power is initially applied, the regulator circuit's input can be 75V or more, while the output can be as low as 1.3V. This is due to REG1's adjust terminal being initially held at 0V via a 1µF bypass capacitor.

Since the LM317 cannot cope with this admittedly brief overload, a pre-regulator comprising Darlington transistor Q1 and 33V zener diode ZD1 is used to protect it from over-voltage. Q1 acts as an emitter follower, while ZD1 has its anode connected to REG1's output, thereby limiting the voltage across the regulator to about 31.7V (after allowing for the voltage drop across the two base-emitter junctions in Darlington transistor Q1).

Following the pre-regulator, the circuit involving REG1 is fairly standard. REG1's supply input is decoupled using a 100nF MKT capacitor, while the output and adjust terminals are bypassed using 1µF 63V electrolytic capacitors.

The minimum load current for REG1 to give its specified performance is 12mA. Since the voltage between the output and adjust terminals could be as low as 1.2V, we would normally connect a 100Ω resistor between these two terminals to provide this minimum current. However, this wouldn't allow us to use convenient standard resistor values for the adjust-to-ground resistors and so we have used a 150Ω resistor instead. This provides a minimum load of 8mA, with the remaining 4mA required being added by the current through power indicator LED1.

In fact, assuming a 48V output and 2V across LED1, the LED current will actually be 4.6mA.

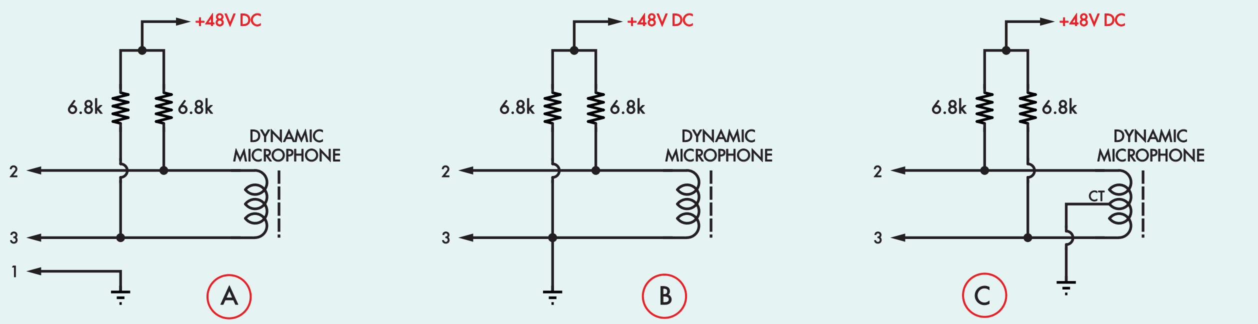
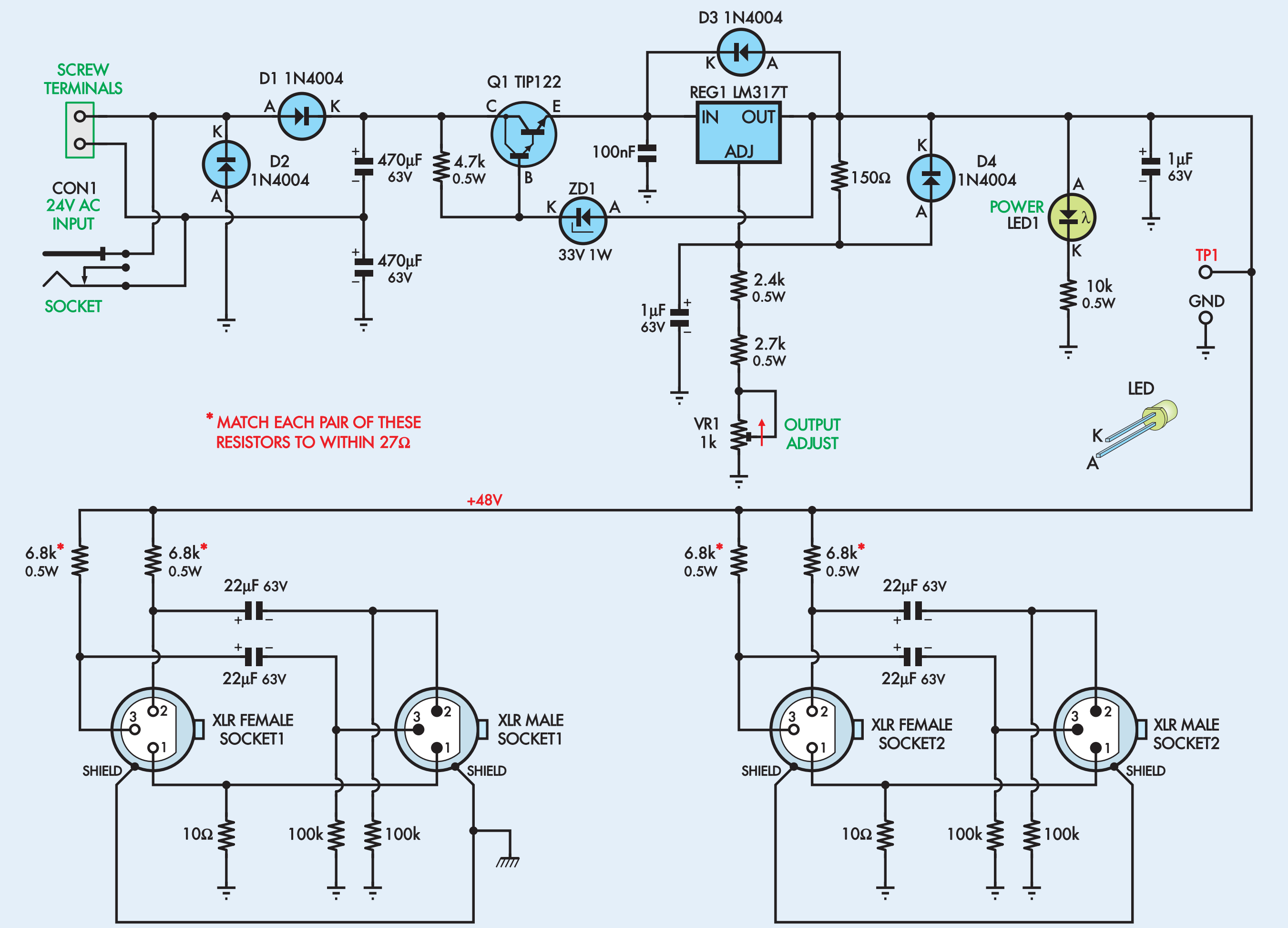


Fig.2: a correctly wired dynamic microphone coil is shown at (A) but problems occur if the microphone is incorrectly wired as shown at (B) and (C) due to current flowing in the coil.



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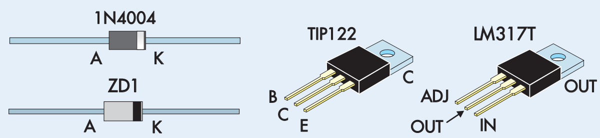


48V DUAL PHANTOM POWER SUPPLY

Fig.3: the circuit of the *48V Dual Phantom Power Supply.* The 24V AC supply input is rectified by voltage doubler D1 and D2 and fed to an LM317T adjustable regulator (REG1) via a pre-regulator consisting of Darlington transistor Q1 and ZD1. The resulting 48V DC output from REG1 is then fed to pins 2 and 3 of the female XLR sockets via 6.8kΩ resistors.

Trimpot VR1 (1kΩ) allows the output voltage to be adjusted from 40.8V to 48.8V if the output-to-adjust terminal voltage is at its 1.2V minimum. If the output-to-adjust terminal voltage is at its 1.3V maximum, the current through the adjust resistors is 8.66mA and the output voltage can be adjusted using VR1 from 44.2V to 52.8V.

These calculations do not include the current flowing from the adjust terminal itself. This is typically 45µA, but can be as high as 100µA. For the adjust terminal to ground resistance used, this can add an extra 0.61V to the output.

Note that the output voltage is required to be between 44-52V in order for the phantom supply to comply with the DIN EN 61938 standard.

Diodes D3 and D4 are included as standard protection. D3 allows current flow from the output back to the input if the regulator's input is shorted. Similarly, D4 allows current to flow from the 1µF bypass capacitor at the adjust terminal if the output is shorted.

XLR sockets

The 48V DC supply is fed to the XLR sockets via 6.8kΩ resistors. These limit the short-circuit current to a nominal 7mA (6.5-7.7mA range) for each supply pin (pins 2 and 3 on the XLR sockets). Ideally, each 6.8kΩ resistor pair should be matched to within 27Ω to comply with the 0.4% tolerance allowed by the phantom power specifications. That can be easily achieved by using resistors that are from the same manufacturer's batch.

In practice, the resistor values are checked with a digital multimeter before installation. The resistors in each pair do not need to be within 27Ω of 6.8kΩ; just within 27Ω of each other.

As mentioned previously, 22µF electrolytic capacitors are used to block the 48V DC on the balanced signal lines from being fed to the XLR male output sockets, and these work in company with 100kΩ bias resistors from the outputs to ground. The 22µF capacitors ensure a low-frequency roll-off that's well below 20Hz for a typical sound mixer or amplifier input impedance

of 10kΩ. The 10Ω resistors isolate the ground connections between each pair of female and male XLR sockets to prevent high-level ground loop currents.

By contrast, the shield connections of each XLR socket pair are connected together (but not to each other). In other words, the Female Socket1 shield connects to the Male Socket1 shield and the Female Socket2 shield connects to Male Socket2 shield. There is no interconnection between the two sets of shields.

In practice, the Socket1 pair shield is also connected to the metal case used to house the circuit. This connection is made via one of the mounting screws that's used to secure the XLR female socket to the case.

Construction

The *48V Dual Phantom Supply* is built on a double-sided plated-through PCB, which is availble from the *EPE PCB Service*, coded 18112141 and measuring 56.5 × 113mm. This is housed in a diecast box measuring 122 × 66.5 × 39mm and a panel label (113 × 56mm) is affixed to the lid.

Fig.4 shows the parts layout on the PCB. Begin by installing the resistors, zener diode ZD1 and diodes D1-D4. A digital multimeter should be used to check the resistor values before they are installed. As mentioned above, you will need to select two pairs of 6.8kΩ resistors that are within 27Ω of each other.

Make sure the diodes are all installed with the correct polarity. The banded end of each diode must be oriented as shown on the layout diagram.

The PC stakes for TP1 and GND can go in next, followed by REG1 and Q1 (don't get these latter two parts mixed up). As shown, REG1 and Q1 are mounted horizontally, with their leads bent down by 90° so that they go through their respective PCB holes. Be sure to secure the metal tab of each device to the PCB using an M3 × 6mm machine screw and nut before soldering their leads.

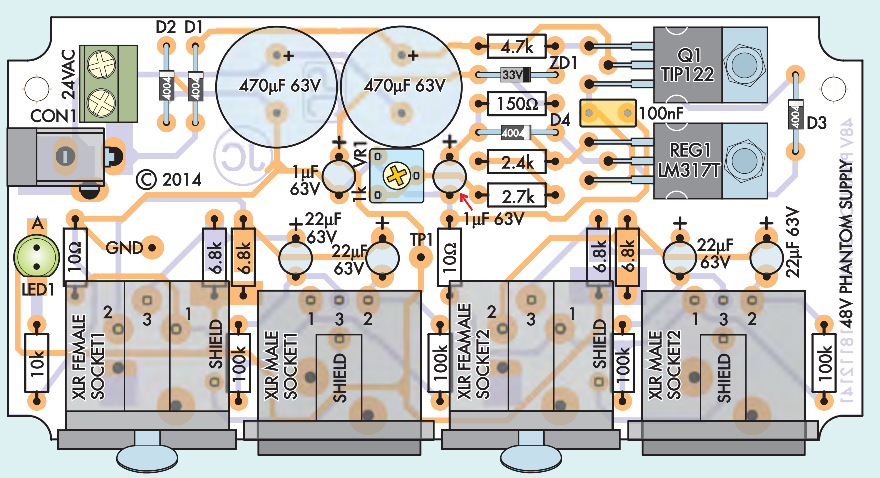
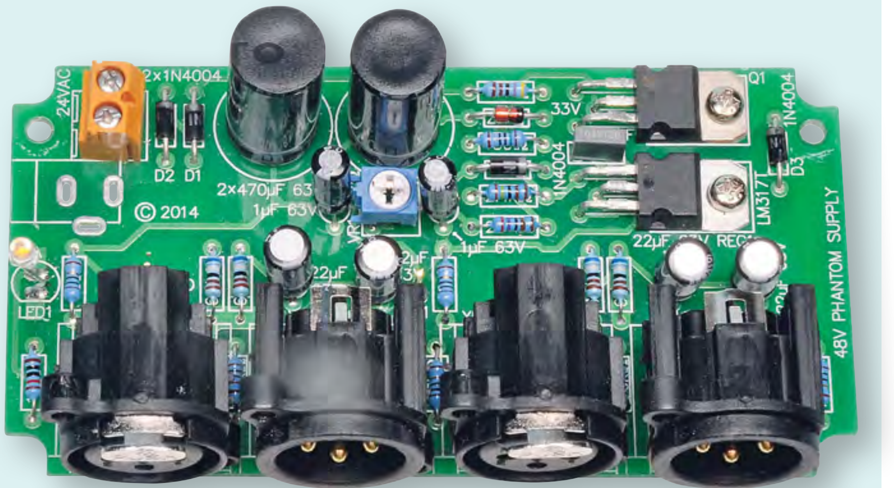


Fig.4: follow this diagram to install the parts on the PCB. LED1 should be mounted with the top of its lens 30mm above the board so that it will later protrude through the lid of the case.



This view shows the completed PCB assembly. Note that the top of each 470µF capacitor must be covered with insulating tape (12mm-diameter) to ensure that they cannot later short to the case lid.

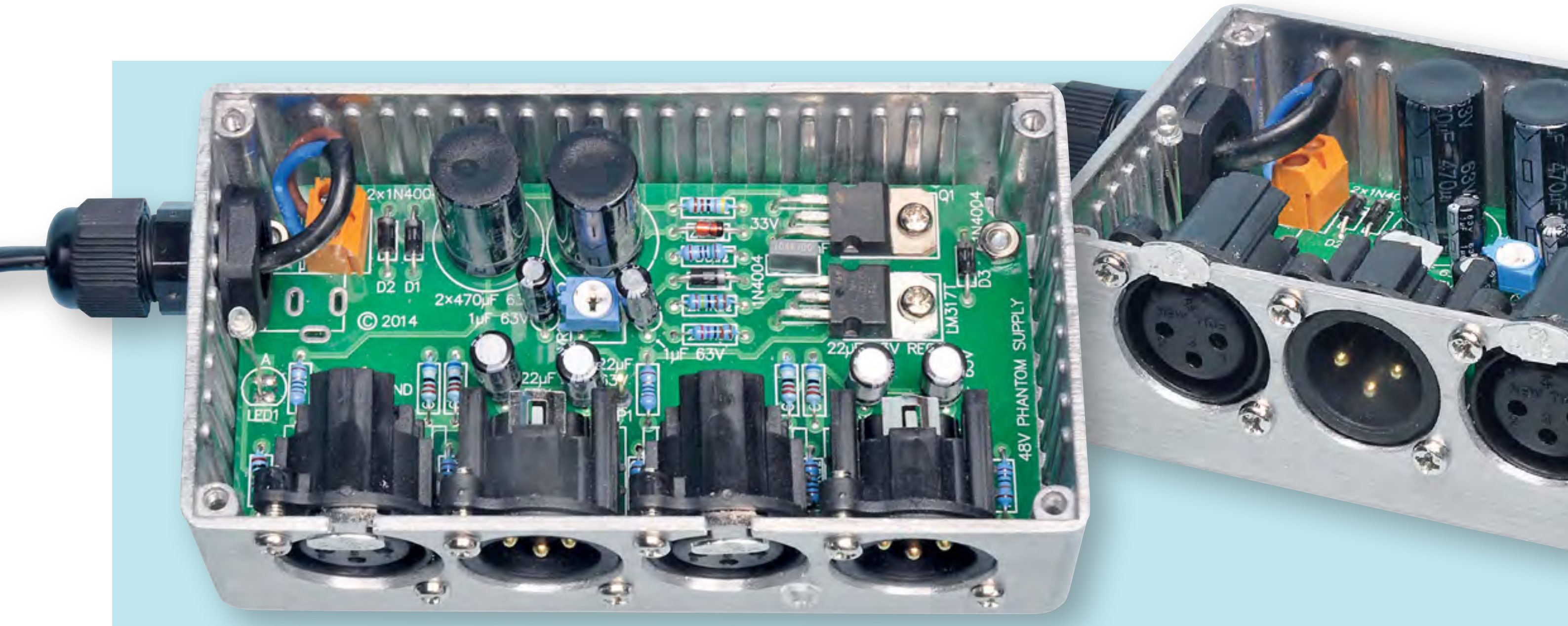
Trimpot VR1 can now be installed, followed by the capacitors. Make sure the electrolytics are installed with the correct polarity.

The 2-way screw terminal block (CON1) is next on the list (wire entry holes towards the adjacent edge of the PCB). Alternatively, a DC socket can be fitted instead. A screw terminal block would normally be used, since AC plugpacks are usually supplied with bare leads.

Next, install the XLR sockets – make sure that they all sit flush against the PCB before soldering their leads. LED1 can then go in; it must be fitted with

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	4	100kΩ	brown black yellow brown	brown black black orange brown
❏	1	10kΩ	brown black orange brown	brown black black red brown
❏	4	6.8kΩ	blue grey red brown	blue grey black brown brown
❏	1	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❏	1	2.7kΩ	red violet red brown	red violet black brown brown
❏	1	2.4kΩ	red yellow red brown	red yellow black brown brown
❏	1	150Ω	brown green brown brown	brown green black black brown
❏	2	10Ω	brown black black brown	brown black black gold brown



The PCB is installed in the case by mounting it on two M3 × 6mm tapped spacers (secured with M3 × 12mm countersink screws) at the rear and by fitting six M3 × 12mm screws (one nylon, the rest metal) into the XLR sockets at the front.

the correct polarity and with the top of its lens 30mm above the PCB so that it later just protrudes through the lid of the case. Note that the longer lead is the anode.

The PCB assembly can now be completed by covering the top of each 470µF capacitor with a circular piece of insulating tape cut to a diameter of 12mm. This is necessary to ensure that the capacitors cannot later short to the lid of the case.

Test and adjustment

Before going any further, check that all components are oriented correctly and that you haven't missed any solder joints. That done, apply 24VAC power and check that LED1 lights.

If it does, connect your multimeter between TP1 and GND and adjust trimpot VR1 for a reading of 48V. Check that 48V is also present at pins 2 and 3 of the XLR female sockets; ie, by measuring between each pin and GND.

Now check pins 2 and 3 of the XLR male sockets. They should each be at a low voltage and this should continue dropping over time as the 22µF capacitors fully charge. In fact, they may take several minutes to drop below 50mV, due to capacitor leakage current. If the voltage on one or more pins remains higher than 100mV, change the relevant capacitor. You can use low-leakage 50V capacitors if necessary.

Preparing the box

Before installing the PCB in the case, it's necessary to drill mounting holes for the XLR sockets and the two rear PCB mounting points. A hole is also required is the lefhand side of the case to accept a cable gland (for the 48VAC supply leads) or a DC plug, while a 3mm hole must be drilled in the lid for the power indicator LED.

Fig.5 shows the drilling template for the XLR sockets, while Fig.6 (the front panel artwork) shows the location of the LED (these can also be downloaded in PDF format from the *EPE* website).

As shown, the XLR sockets require 22mm-diameter clearance holes, with 3mm-diameter holes for the mounting screws. The 22mm holes can be easily cut using an Irwin Speedbor or similar drill. These are intended for use in timber, but they also work well on aluminium.

Drill just down to a depth where the internal ribs of the box begin; any further and the drill will begin to wobble. The inside piece can then be forced sideways in several directions by inserting a screwdriver in the centre hole and applying leverage. Do this until the inside piece eventually gives way and falls out, then clean up the hole with a round file.

If you don't have a Speedbor drill, drill a series of small holes around the inside perimeter of the hole, then knock out the centre piece and file the job to a smooth finish.

Each XLR female socket also requires a cut-out between the top of its 22mm hole and the top edge of the box (see Fig.5). This cut-out is necessary to allow the 'push to release' lever on each XLR female socket to be inserted. It's just a matter of making these cut-outs using a hacksaw after the 22mm holes have been drilled.

The two mounting holes for the rear of the PCB are marked out after the XLR cut-outs have been made. It's just a matter of temporarily fitting the PCB assembly into the case, marking out the two holes, then removing the PCB and drilling them to 3mm. Deburr the holes using an oversize drill, then countersink them from the outside to suit countersink-head M3 screws.

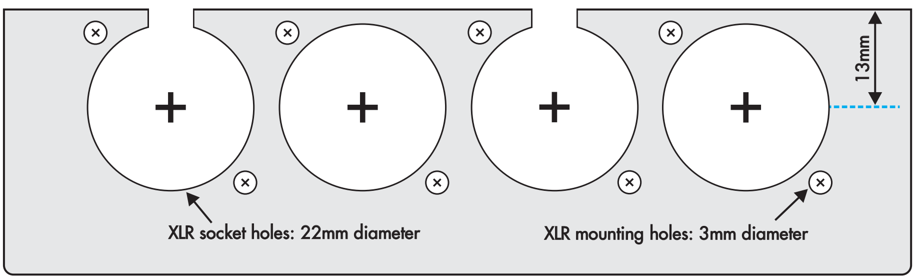


Fig.5: the drilling and cutout template for the front side of the case. This can also be downloaded in PDF format from the *EPE* website.

Next, drill the hole in the side of the case for the power cable (either to accept a cable gland or a DC power plug). This hole should be positioned towards the rear of the case; it must be directly in-line with the DC socket (if used).

Final assembly

Once all the holes have been drilled, the PCB assembly can be mounted in the case. The first step is to install two M3 × 6mm tapped spacers to support the rear edge of the PCB. Secure these using M3 × 12mm countersink head screws inserted up through the base of the case, then drop the PCB into position and fit nuts to hold the assembly in place.

The PCB assembly is secured to the front of case by fitting M3 × 12mm mounting screws to the XLR sockets. **Seven of these screws are metal but a nylon screw must be used for the lower (righthand) mounting hole of XLR female socket2 (see photos).** This is necessary to prevent the screw from making a connection between this socket's shield and the case, thereby creating an earth loop (and causing hum). That's because the lower mounting hole of each female socket connects the shield to the case when a metal screw is used.

By the way, you will have to cut a thread in the plastic of XLR female socket2 with one of the M3 metal screws before replacing this with the nylon screw. Do all the screws up so that there is a gap of about 2.5-3mm between the socket and the case, so that the lip on the inside of the lid will fit between them.

Front panel label

The front-panel label can be produced by printing it onto photo paper. This is then affixed to the case lid using a suitable glue or neutral-cure silicone and the hole cut out for the LED.

For a more rugged label, print a mirror image onto clear overhead projector film, so the print side will be on the back of the film when the label is affixed to the lid (eg, using silicone sealant). Alternatively, you can print onto an A4 sized synthetic 'Dataflex' self-adhesive label if you have an inkjet printer or onto a 'Datapol' self-adhesive label if you have a laser printer. Further information on where to buy these labels is in the panel in the **Mains Switch Timer** article published elsewhere in this issue.

Once the label is in place, it's then just a matter of attaching the lid using the four countersunk M3 screws provided and the *48V Dual Phantom Power Supply* is ready for use.

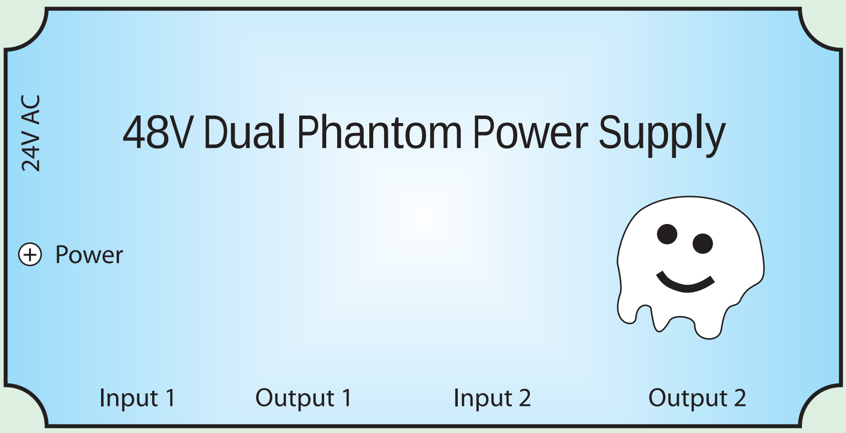


Fig.6: the front-panel artwork is also available on the *EPE* website. You will need to drill a hole in the case lid for the power LED.

Parts List

- 1 PCB, code 18112141, 113 × 56.5mm, available from the *EPE PCB Service*
- 1 panel label, 113 × 56mm
- 1 diecast box 122 × 66.5 × 39mm
- 1 24V AC plugpack (50mA minimum rating)
- 2 XLR female 3-pin connectors (compact, PCB mount, 90°) 0875) (Female Socket1, Female Socket2)
- 2 XLR male 3-pin connectors (PCB-mount, 90°) (Male Socket1,Socket2)
- 1 2-way PCB-mount screw terminal block with 5.08mm spacings (CON1)
- 1 cable gland (3-6.5mm dia. cable)
- 1 PCB-mount DC socket, 2.1mm or 2.5mm
- 2 M3 × 6mm spacers
- 2 M3 × 10mm machine screws (to secure REG1 and Q1)
- 7 M3 × 12mm machine screws (for XLR socket mounting)
- 1 M3 × 12mm nylon or polycarbonate screw (lower right female XLR socket mounting)
- 2 M3 × 12mm countersink-head screws (rear PCB mounting)
- 4 M3 nuts
- 2 PC stakes
- 1 25mm length of insulation tape
- 1 1kΩ mini horizontal trimpot (VR1)

Semiconductors

- 1 LM317T adjustable regulator (REG1)
- 1 TIP122 NPN Darlington transistor (Q1)
- 4 1N4004 1A diodes (D1-D4)
- 1 33V 1W zener diode (ZD1)
- 1 green 5mm LED (LED1)

Capacitors

- 2 470μF 63V PC electrolytic (26.5mm height maximum)
- 4 22μF 63V PC electrolytic
- 2 1μF 63V PC electrolytic
- 1 100nF MKT polyester

Resistors (0.25W, 1%)

4 100kΩ	1 2.7kΩ 0.5W
1 10kΩ 0.5W	1 2.4kΩ 0.5W
4 6.8kΩ 0.5W*	1 150Ω
1 4.7kΩ 0.5W	2 10Ω

* Select each pair to be within 27Ω of each other

Programmable mains timer with remote switching

Remote-controlled mains switches are very convenient but what if you could add a versatile easy-to-program timer to one of these units? Well, now you can. This *Remote Switch Timer* can be programmed to switch the power on and off after a set period or to switch the power on and off at set times.

By JOHN CLARKE

MAINS TIMERS are ideal for switching appliances at predetermined times. Their complexity ranges from simple mechanical timers with a synchronous motor and switch actuator cams through to complex menu-driven fully-electronic timers, which tend to have fiddly buttons and can be difficult to program. However, none have the advantage of remote control, whereby the timer is remote from the actual mains-switched power socket.

To give an example, say you have an appliance in your garage that you want to control with a mains timer. Wouldn't it be nice if you could program and control the timer without having to be in the garage? This idea can be extended to a lot of applications.

To meet this need, we've devised this *Remote Switch Timer*. It's designed to work with just about any commercially-available remote control mains socket (provided the hand-held remote is powered by a 12V battery). Basically, it interfaces with the remote's PCB and provides the extra timing functions. The remote then automatically switches the mains socket on and off, as required.

As shown in the photos, the *Remote Switch Timer* is housed in a plastic box, along with the PCB from the remote. It has 10 pushbutton switches and a 2-line LCD which has a dimmable backlight for night-time use. The front-panel buttons are used to program and control the unit.

Remote control mains sockets

For those unfamiliar with these devices, a remote control mains socket consists of a mains plug and piggyback socket, together with a relay and UHF receiver inside the plastic housing. It is controlled using a UHF hand-held remote control, which is used to switch the mains socket on and off.

Both 3-channel and 8-channel remotes are typically available, and these come either with a single socket

The Jaycar remote controlled mains switch comes with a 3-channel hand-held remote. MS-6142 comes with three mains sockets, while MS-6145 has one socket. *UK readers must ensure they use a UK-socket version (see text).*

The Altronics A0340 has an 8-channel remote control and is supplied with a single mains socket. Additional mains sockets can be purchased separately.

or with a number of sockets. Alternatively, the additional sockets have to be purchased separately. The remote controls each socket individually and it's just a matter of either using a learning procedure to set the socket's channel number or setting a channel switch on the rear of the socket.

The Altronics A0340, Jaycar MS-6145 and Jaycar MS-6142 are typical of the units currently available. **(UK readers will of course need a UK version, eg, eBay number 331065350352.)**

How does it work?

This *Remote Switch Timer* is designed to activate any pair of on/off switches on the remote control. It does this by controlling two small relays which have their contacts wired across the desired on and off switches on the remote's PCB.

Basically, it's just a matter of removing the remote's PCB from its case and housing it together with the *Remote Switch Timer* inside a plastic utility case. The two are then wired together and powered from an external 12V DC plugpack and an optional internal 9V back-up battery.

As well as using the new automatic timing functions, you can still manually control the mains socket using separate On and Off pushbuttons on the *Remote Switch Timer*. Alternatively, another hand-held remote can be used.

In preset-time mode, the *Remote Switch Timer* is used to send an 'on' or 'off' signal to the remote mains socket after a set period of time. You simply program when you want the socket to switch on or off and then press the Set/Start button. The timer then automatically switches after the preset time, which can range from a minimum of one minute to a maximum of 255 hours and 59 minutes (that's more than 10 days!).

During the time-out period, the displayed time decreases by one every minute until the timer reaches zero. The relay for that timer function then closes and the UHF signal from the remote is sent to the mains socket.

To set the time-out period, you first select either the On or Off timer using the Next pushbutton. The separate Up and Down hours and minutes pushbuttons are then used to set the required timing period.

If you want more complexity, the *Remote Switch Timer* can use both its timers. One timer can be set to turn the mains socket on after a preset time, while the other can be set to then turn it off (or vice versa). In addition, the On and Off pushbuttons can be used to set the initial status of the remote control mains socket; ie, you can start with the mains power on or off.

Default timing cycle

The default timing cycle for the unit is for it to run once only. This is where the timers are set to their required values and decrease over time until they reach zero. Once a timer has counted down to zero, there is no more control from that timer unless it's set to a new value.

Note that the timer will just show dashes when the time-out is zero.

The default setting can be changed from 'once only' to 'repeat'. This is where the timers are returned to their original settings after both timers have timed out.

As an example, let's say that you've set the On timer to two minutes and the Off timer to three minutes. This means that after two minutes, the On timer will have counted down to zero and sent an 'on' signal to the mains socket to turn on the power. The Off timer now continues to count down and when it too reaches zero (ie, after one minute more), an 'off' signal will be sent to the mains socket. Both timers will then be reset to their original 2-minute and 3-minute settings and so the cycle repeats every three minutes.

The on and off timers for this countdown style of timing are called the 'ON IN' and 'OFF IN' timers (ie, on in a certain period and off in a certain period). The once only and repeat timer options are predictably named 'ONCE ONLY' and 'REPEAT'.

This style of timer is quite useful (and simple to use) for many timer applications. However, for even more flexibility, a 'real-time' timer mode is also included. This is similar to setting an alarm clock and allows you to set the time of day for the on/off switching to occur.

In order to do this, a real-time clock is required and the one used here is in 24-hour format.

Parts List

1 double-sided, plated-through PCB, available from the *EPE PCB Service*, code 19112141, 104 × 76mm
1 front panel PCB, code 19112142, 157 × 94mm* OR
1 front panel label, 144 × 84mm*
1 UB1 plastic utility case, 158 × 95 × 53mm*
6 M3 × 9mm tapped spacers*
1 LCD module with backlighting (Altronics Z-7013, Jaycar QP-5512 or similar)
1 UHF remote-controlled mains switch with 12V powered remote controls (eBay: item 331065350352; amazon.co.uk: search under 'Watts Clever')
2 SPST DIP 5V reed relays (RLY1,RLY2)
1 4MHz low-profile crystal (HC49US case) (X1)
10 click-action pushbutton PCB switches (white)
1 12V DC plugpack (>100mA)
1 16-way SIL pin header with 2.54mm pin spacing
1 panel-mount DC socket (2.1 or 2.5mm to suit plugpack)
4 2-way polarised headers (2.54mm pin spacing)
4 2-way polarised header plugs (2.54mm pin spacing) (CON1-CON4)
12 M3 × 5mm machine screws (2 preferably countersunk for the rear of the box)
1 100mm cable tie
1 400mm length of medium-duty black hook-up wire
1 200mm length of medium-duty red hook-up wire

Semiconductors
1 PIC16F88-I/P microcontroller programmed with 1911214A.hex (IC1)
1 LP2950ACZ-5.0 low-dropout 5V regulator (REG1)
1 BC337 NPN transistor (Q1)
6 1N4148 diodes (D1,D2,D4-D7)
2 1N4004 1A diodes (D3,D8)

Capacitors
2 10µF 16V PC electrolytic
1 100nF MKT polyester
2 33pF C0G (NP0) ceramic

Resistors (0.25W, 1%)
1 100kΩ
1 330Ω 0.5W
1 10kΩ
2 100Ω
1 2.2kΩ
1 10kΩ miniature horizontal trimpot (VR1)

***Alternative enclosure parts**
1 sealed polycarbonate case with clear lid 115 × 90 × 55mm
1 front panel label, 103 × 78mm
4 M3 × 12mm tapped spacers

Optional parts for battery back-up
1 9V battery snap with lead
1 9V battery (522/6LR61)
1 9V U-clamp battery holder
1 2-way polarised header and plug (2.54mm pin spacing) (CON5)
1 M3 × 6mm machine screw
1 M3 nut

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Real-time switching

For this mode, we call the real-time timers 'ON AT' and 'OFF AT' (ie, on at a certain time and off at a certain time). You can set either one timer or both. The timers are also in 24-hour format and are compared against the time on the clock. When the clock and timers match, an on or off signal is sent to the mains socket.

Note that in this mode, the timer values do not change during the time-out period. Instead, they are simply compared with the clock for a time-out match.

Note that a 00h:00m setting for either timer will show as dashes on the LCD and there is no on or off switching for this setting. 00h:00m also corresponds to midnight, so it is not possible to have the timer switch at precisely midnight. However, switching times one minute before (23h 59m) and one minute after midnight (0h 1m) are possible.

This rather minor shortcoming allows for simplified timer operation because it doesn't require an extra selection as to whether you want a timer to be operational or not.

There are two possible settings for real-time switching: (1) where the sequence occurs once only; and (2) where the on and off cycle is repeated each day. As before, these options are called 'ONCE ONLY' and 'REPEAT'.

For the once-only selection, the timer will revert to zero (with the LCD showing dashes) once that timer has matched the clock. For the repeat selection, the timer will remain at its time setting so that it can repeat the switching sequence each day.

Clock accuracy

The long-term timing accuracy depends on the accuracy of the crystal timebase used in the *Remote Switch Timer*. This in turn is dependent on the crystal tolerance and on temperature variations throughout the year.

For a standard ±50ppm crystal, the clock could be fast or slow by up to 130s (ie, two minutes and 10 seconds) over a period of 30 days. However, the timing accuracy can be easily adjusted by changing a value in the software that runs in the PIC microcontroller used in the *Remote Switch Timer*.

Basically, the *Remote Switch Timer* can be adjusted to run faster or slower in 1ppm steps, up to a maximum of ±99ppm. A 1ppm change represents about 2.6s in 30 days, while the 99ppm maximum adjustment corresponds to 256s in 30 days.

Adjusting the clock accuracy may be necessary if you want the 'ON AT' and 'OFF AT' timers to switch the unit at certain times of the day. However, it will not usually be necessary for the 'ON IN' and 'OFF IN' timers, which are used to switch the unit in a certain time period.

Battery back-up

An option is to include a battery back-up for the *Remote Switch Timer*. That way, all settings will be retained and timing will continue in the event of a black-out or if mains power is removed from the unit.

Of course, the mains socket will not be powered in the event of a blackout and so it will not respond to any on or off signals from the unit. However, when power is restored, the last on or off signal is sent again after a short delay. That way, the mains socket will switch to the required setting for the present time.

Note that the backlighting for the LCD module is switched off to conserve the battery when the unit is running from battery power alone.

Without battery back-up, the *Remote Switch Timer* will reset with all

timers set to zero when a black-out ends. In addition, the mains socket will be reset with the power off.

In summary, it's an incredibly versatile unit that's easy to program. It should cover a very wide range of timing applications.

Circuit details

Take a look now at Fig.1 for the circuit details of the *Remote Switch Timer*. It's quite simple and is based on a PIC16F88-I/P microcontroller (IC1), an LCD module, a couple of miniature relays, 10 pushbutton switches and a few other parts.

Most of the complexity is hidden inside the software that's programmed into IC1. This allows the micro to monitor the switch inputs and drive the LCD module and relays according to the actions required by the switches and internal timers.

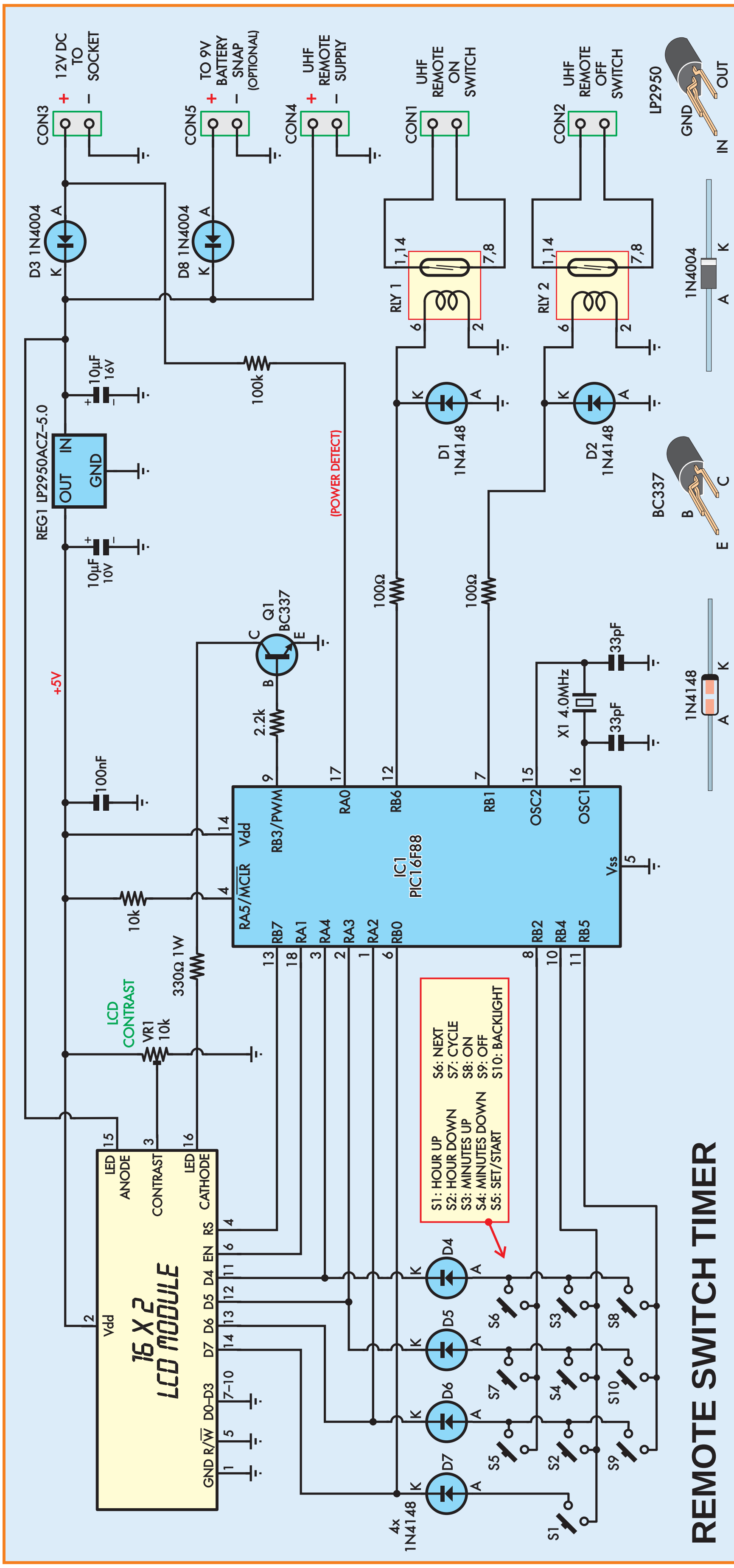
IC1's RA2, RA3, RA4 and RB0 data lines send character data to the LCD module. In addition, the RA1 and RB7 lines drive the Enable (EN) and Register Select (RS) inputs. The LCD is set to run using four bits of data to save on outputs from IC1. The necessary data bits are sent to the LCD as two separate transfers, to make up the eight bits necessary to fully drive the display.

The RA2, RA3, RA4 and RB0 lines also drive a matrix based on pushbutton switches S1-S10 and diodes D4-D7. To check if a switch is closed, the RA2, RA3, RA4 and RB0 lines are driven low and the RB2, RB4 and RB5 inputs monitored. These latter inputs are normally pulled high (to +5V) via internal pull-ups, but one of these inputs will go low (ie, close to 0V) if a switch is closed.

When a low is detected, the RA2, RA3, RA4 and RB0 lines are taken high again and then taken low one at a time while IC1 continues monitoring RB2, RB4 and RB5. This allows the micro to determine which switch button is being pressed. For example, if S3 is closed, this will be detected when RA4 goes low and in turn pulls RB4 low.

Diodes D4-D7 are there to prevent shorts between the RA2, RA3, RA4 and RB0 lines if two switches are pressed at the same time. Shorts between these lines would not only affect switch detection but would also affect the drive signals to the LCD and cause corrupted characters to be displayed.

Ports RB1 and RB6 drive relays RLY1 and RLY2 via 100Ω resistors. The NO



REMOTE SWITCH TIMER

Fig.1: the circuit is based on PIC16F88-I/P microcontroller IC1 and an LCD module. IC1 monitors switches S1-S10, drives the LCD, controls the timing and drives miniature relays RLY1 and RLY2. The relays have their contacts wired across the On and Off buttons of a UHF remote control module.

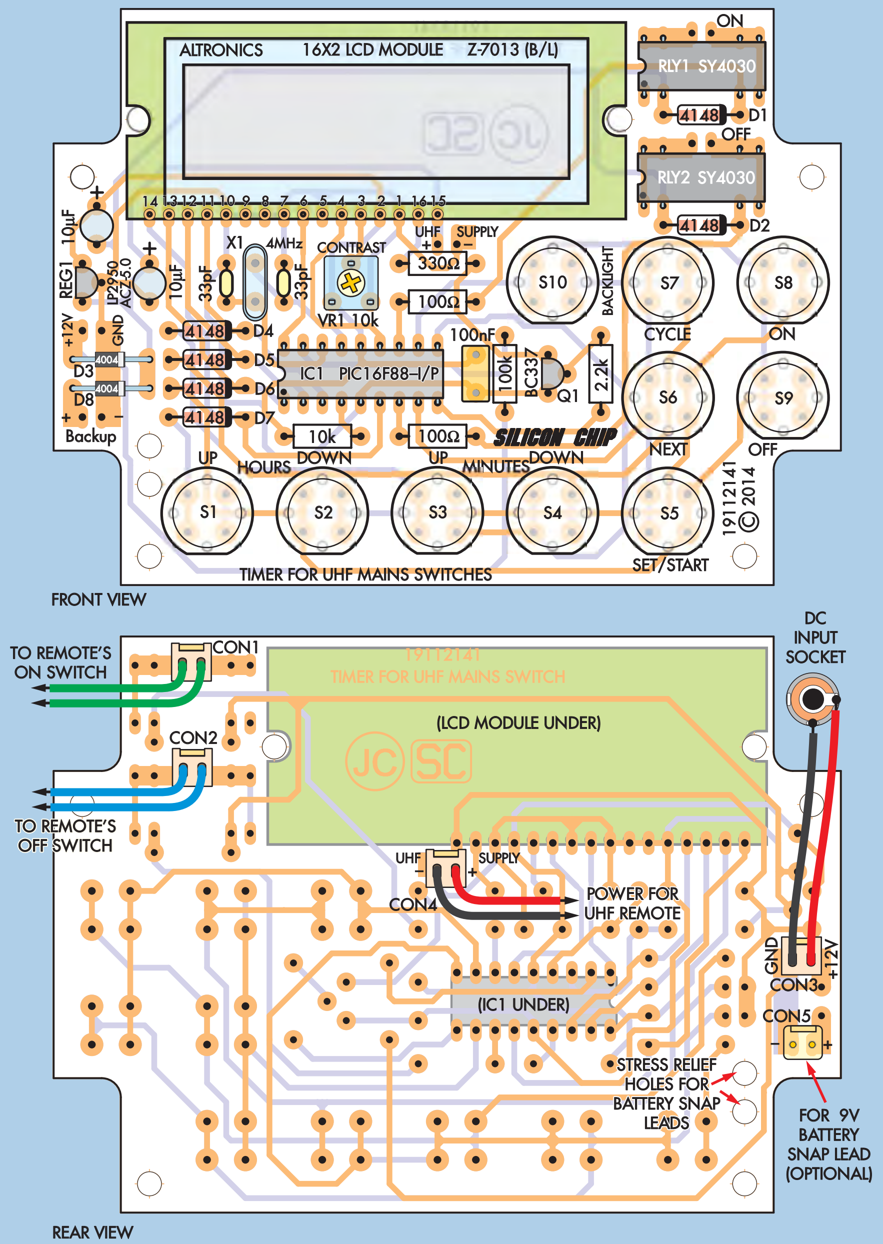


Fig.2: install the parts on the PCB as shown here. Be sure to use a socket for IC1 and make sure that all polarised parts are correctly oriented. The 2-way header sockets (CON1-CON5) are the only parts that mount on the rear of the board.

(normally open) contacts of the relays go to CON1 and CON2 and these in turn are wired in parallel with the ON and OFF switches respectively on the UHF remote's PCB. Diodes D1 and D2 prevent damage to RB1 and RB6 by clamping the back-EMF generated by the coils when the relays switch off.

The 100Ω resistors in series with the relay coils also help protect IC1's RB1 and RB6 outputs. They are not needed in normal operation, but will limit the back-EMF current from a relay coil if its associated diode fails or develops a dry joint connection.

Timing

A 4MHz crystal (X1) between pins 15 and 16 of IC1 is used to provide an accurate reference for the timing oscillator. It's loaded with fixed 33pF capacitors to ensure it starts correctly.

Normally, the crystal would be trimmed to a precise 4MHz using a trimmer capacitor in place of one of the fixed values. However, without suitable calibrated test equipment, it's not possible to accurately adjust the trimmer without a great deal of trial and error. As a result, as previously stated, we chose to use a software adjustment procedure instead.

If the 4MHz crystal is precisely on frequency, the program runs at exactly 1MHz. The software uses a counter (Timer1) that overflows after a count of 40,000 or after 1/25th of a second if the clock frequency is precisely 1MHz (ie, 25 of these 40,000 counts will take 1s).

If the crystal runs too fast or too slow, it's just a matter of altering the 40,000 number used in the counter to provide the correct 1s period. For example, for a 1ppm adjustment, the number for Timer1's overflow counter must either be 40,001 (ie, one more) if the crystal is too fast or 39,999 (ie, one less) if the crystal is too slow.

Note that this change is only done for one of the 25 overflow counts that make up one second for Timer1. The remaining 24 counts still use 40,000 as the count.

As stated, the overall adjustment range is from –99ppm to +99ppm. In operation, the software then adds or subtracts the ppm correction value from 40,000 in order to compensate for the crystal frequency.

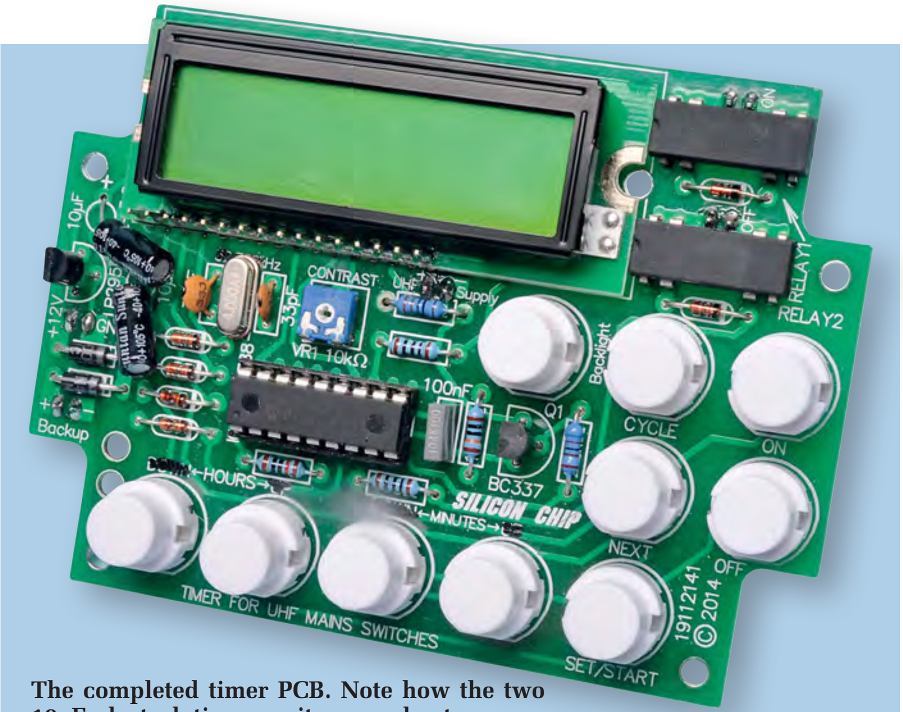
The overflow ppm adjustment is done via the front-panel switches as described later, with the setting shown on the LCD. The correction required is determined by comparing the time of the *Remote Switch Timer* against a known accurate clock over a set period. Each 2.592 seconds in 30 days that it is off is equivalent to 1ppm.

Note that the clock on the *Remote Switch Timer* shows the seconds, so that the clock's accuracy can be checked. The timing functions, however, are only to the nearest minute.

Backlighting

Backlighting is provided for the LCD so that the timer can be used in the dark. This can be adjusted in 16 steps from fully off through to full brightness by pressing the Backlight pushbutton (S10). This brings up the backlighting value which is shown as a number ranging from 0-15, with 15 being full brightness. A bargraph is also used to show the brightness setting.

For brightness levels between 1-14, the backlight LEDs are driven using PWM (pulse-width modulation). Pin 9 (PWM) of IC1 provides the PWM waveform and this drives the cathodes of the backlight LEDs via transistor Q1 and a 330Ω current-limiting resistor.



The completed timer PCB. Note how the two 10µF electrolytic capacitors are bent over so that they don't later foul the lid of the case.

For level 0, there is no drive to the LED cathodes (Q1 permanently off) and for level 15, the LEDs are continuously driven (Q1 permanently on). At other levels, the duty cycle of the PWM pulse determines the LED brightness. At half brightness, for example, the LEDs are switched on and off via Q1 using a 50% duty cycle.

The PWM frequency is 66.66kHz, so the on and off switching of the LEDs will not be noticeable.

The contrast of the LCD module is adjusted using VR1. It's just a matter of tweaking VR1 to suit.

Power supply

The *Remote Switch Timer* is normally powered from a 12V DC plugpack supply connected to CON3. Diode D3 provides reverse polarity protection and the nominal 11.4V supply rail is then filtered using a 10µF capacitor and used to power the backlight LEDs in the LCD module.

The 11.4V rail is also fed to low-dropout regulator REG1. This produces a regulated 5V rail to power microcontroller IC1, the LCD module and the remaining circuitry.

The optional 9V back-up battery is connected to CON5. Diode D8 provides reverse polarity protection and both it and D3 isolate the two supplies.

IC1's RA0 input (pin 17) monitors the 12V supply line from CON3. If this goes to 0V, but IC1 is still powered via the back-up battery, the software detects this loss of 12V power and switches off the backlight. When the 12V is subsequently restored, this is detected by RA0 and the last ON or OFF signal is resent to the remote PCB by turning on the appropriate relay.

In practice, the ON or OFF relay is activated about 3s after power is restored and remains on for around 900ms. This 3s delay gives enough time for the remote control circuit to power up and for the companion mains socket to power up if there has been a blackout.

Construction

All the parts (except for the UHF remote) are installed on a PCB coded 19112141 and measuring 104 × 76mm, which is available from the *EPE PCB Service*. Fig.2 shows the parts layout on the PCB.

Begin by installing the resistors and diodes. Table 1 shows the resistor colour codes, but we recommend that you also check each one using a DMM before installing it. Be sure to install the diodes with the correct polarity.

REG1 and Q1 are next on the list. These two devices look the same, so be careful not to get them mixed up. Once they're in, install an 18-pin socket for IC1, with the notched end towards D5.

Follow with the capacitors. The two 10µF electrolytics must be installed with the polarity shown and bent over so that they lie flat against the PCB, so that they later sit below the top edge of the LCD module (see photo). The ceramic and MKT capacitors can be mounted either way around.

Crystal X1 and trimpot VR1 can now go in, followed by the two relays. Note that each relay must be installed with its notched end towards the LCD.

Now for the LCD module. This is mounted using a 16-way SIL pin header at the bottom lefthand edge. Begin by fitting the header in place with its short pins going into the PCB. Solder these pins, then fit the LCD module over the longer pins and push it all the way down before soldering these pins as well.

Table 2: Capacitor Codes

Value	µF Value	IEC Code	EIA Code
100nF	0.1µF	100n	104
33pF	NA	33p	33

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	1	100kΩ	brown black yellow brown	brown black black orange brown
❏	1	10kΩ	brown black orange brown	brown black black red brown
❏	1	2.2kΩ	red red red brown	red red black brown brown
❏	1	330Ω	orange orange brown brown	orange orange black black brown
❏	2	100Ω	brown black brown brown	brown black black black brown

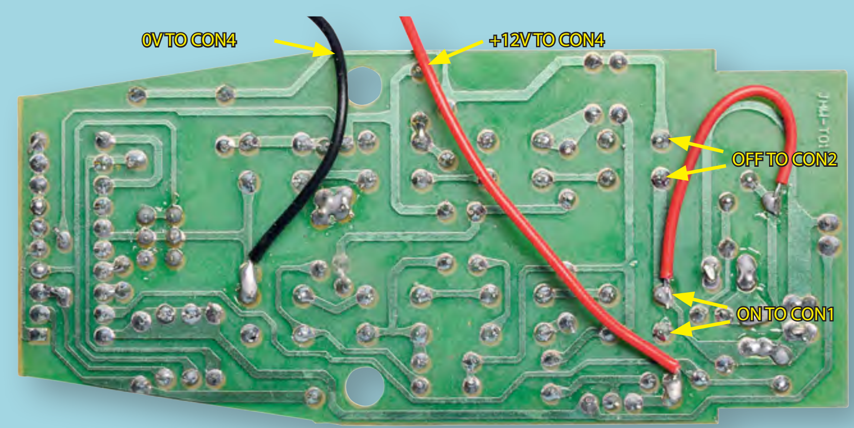
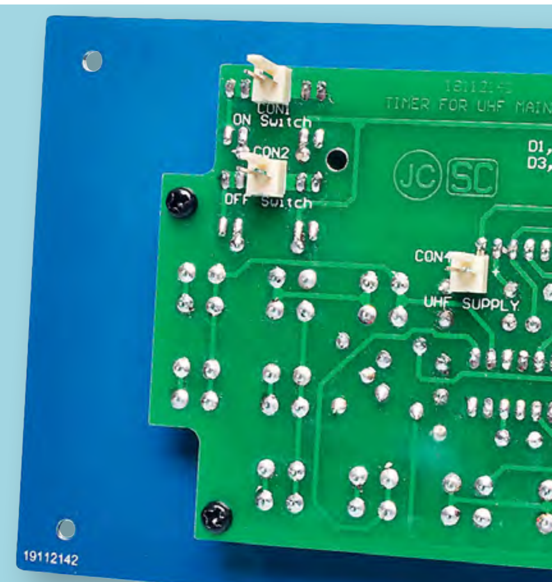


Fig.3: here's how to make the connections to the Altronics UHF remote PCB. The red and black leads shown are all part of the original wiring.



The timer PCB is mounted on spacers on the rear of the front panel and is secured using eight M3 × 6mm machine screws.

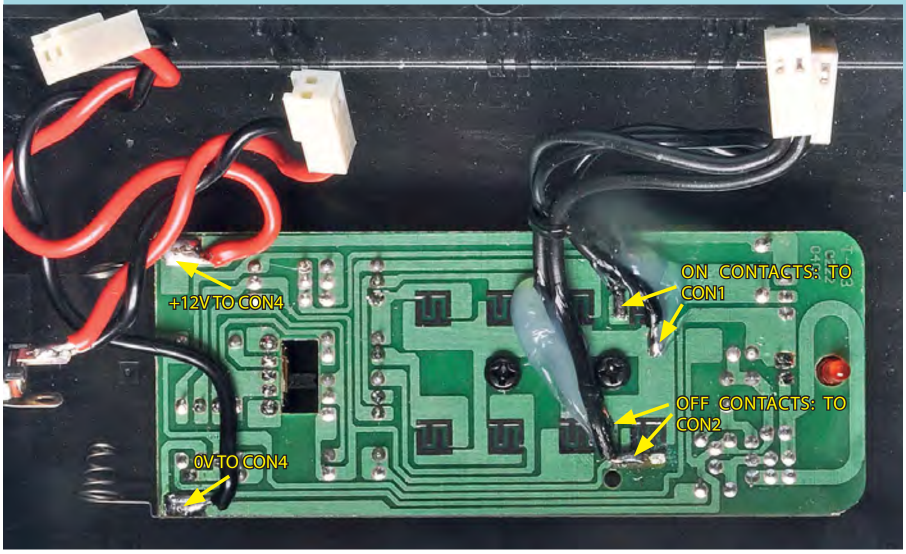


Fig.4: the wiring connections to the Jaycar UHF remote. You will need to scrape away the solder masking from some of the tracks before soldering the leads.

The 10 pushbutton switches can now be installed. These go in with their flat sides oriented as shown and must be pushed all the way down before soldering their pins.

The PCB assembly can now be completed by installing CON1-CON5. These polarised 2-way headers are installed on the rear of the PCB with their plastic tabs oriented as shown in the bottom diagram of Fig.2.

Wiring the header sockets

The header sockets are wired by crimping the wires into the crimp lugs and then pushing them into the socket shell. These wires can all initially be about 100mm long and you will need to use red and black leads for CON3-CON5 as shown. The leads for CON1 and CON2 run to the ON and OFF switches on the remote PCB, so their polarity is unimportant.

Test and adjustment

Before applying power, make sure that IC1 is out of its socket and that all polarised parts are correctly oriented. That done, apply 12V DC to CON3 and use a DMM to check the supply between pins 14 and 5 of IC1's socket. This should be somewhere between 4.75V and 5.25V.

If this is correct, switch off, install IC1 (notch towards D5) and reapply power. The LCD should now show characters. Adjust VR1 for best contrast, then switch the backlight on by pressing the backlight button (S10). Check that brightness can be adjusted by holding S10 down (the adjustment direction changes each time you press S10).

Now press the On button (S8). A click from the ON relay should immediately be heard and the top line of the LCD should display 'ON'. Similarly, pressing the Off button should briefly turn the OFF relay on and cause 'OFF' to be displayed on the bottom line of the LCD.

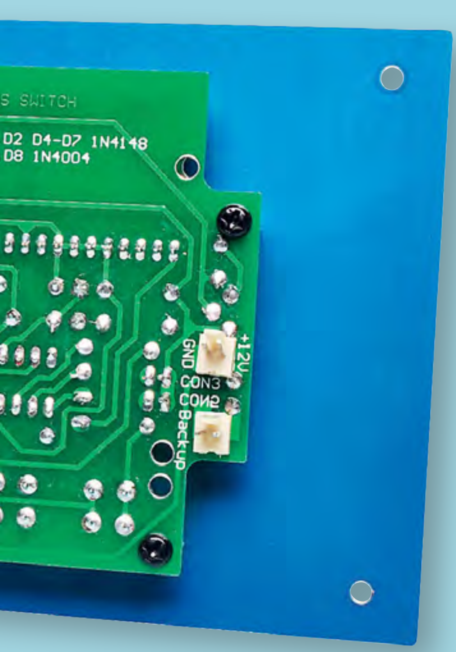
If the unit passes these tests, then it is almost certainly fully functional and it can be installed in a case, along with the remote's PCB module. If it doesn't work, go back over the PCB and check carefully for incorrect component values, incorrectly oriented parts and missed solder joints.

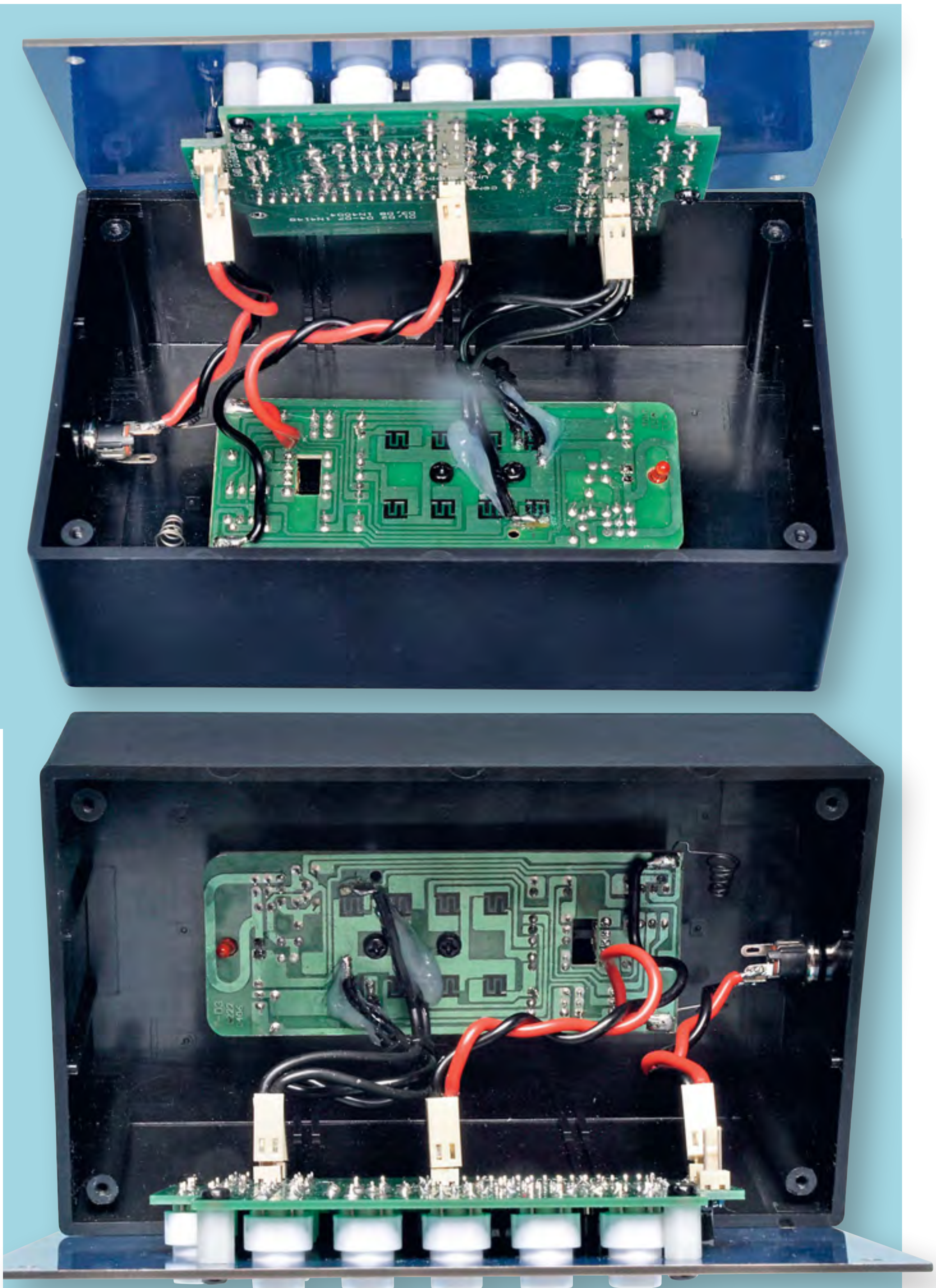
Case installation

The PCB can be installed either in a UB1 plastic utility case (158 × 95 × 53mm) or in a sealed polycarbonate case with a clear lid (115 × 90 × 55mm). A front panel PCB coded 19112142 and measuring 157 × 94mm can be used with the UB1 box. This PCB replaces the plastic lid and comes with all holes drilled and screen-printed lettering. It's available from *EPE*, as is the main PCB.

Alternatively, a label measuring 144 × 84mm can be used with the existing lid on the UB1 box. A front panel label measuring 103 × 78mm is also available for the polycarbonate box. These labels can be downloaded in PDF format from the *EPE* website and printed out.

You will need to print out two copies – one onto plain paper for use as a drilling template and another onto photo paper to use as the front-panel label. The labels show the screw-mounting locations for the PCB on the lid, along with the switch locations. A





Above: these two views show the inside of the unit with all wiring completed (Jaycar remote PCB used, no back-up battery fitted). Use neutral-cure silicone or hot melt glue to hold the wiring to the remote PCB in place.

Dataflex & Datapol Labels

(1) For Dataflex labels, go to:
www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_60&products_id=335

(2) For Datapol labels go to:
www.blanklabels.com.au/index.php?main_page=product_info&cPath=49_55&products_id=326

rectangular cut-out for the LCD surround will also be required for the UB1 box, but this isn't necessary for the polycarbonate case with the clear lid.

The PCB mounting holes should be drilled to 3mm, while the switch holes should be started using a pilot drill and then carefully enlarged to 10mm using a tapered reamer. The rectangular display cut-out can be made in the UB1 box lid by first drilling a series of holes around the inside perimeter, then knocking out the centre piece and filing to a smooth finish.

Once the holes have been drilled, the front-panel label can be affixed to the lid using a suitable glue or neutral-cure silicone. Alternatively, you can print onto an A4-size synthetic 'Dataflex' sticky label if you have an inkjet printer or onto a 'Datapol' sticky label if you have a laser printer. This can then be trimmed to size and affixed to

Features and Specifications

- **Power: 12V DC at 30mA**
- **Current: 30mA with full backlighting; 3mA with backlighting off**
- **Battery backup current: typically 3mA**
- **On and Off IN: adjustable from 0h 0m to 99h 59m in one-minute steps**
- **On and Off AT: adjustable from 0h 0m to 23h 59m (0h 0m shown as ---:– and timer is off)**
- **Real Time Clock: 24-hour format with hh:mm:ss**
- **Crystal tolerance compensation: ±99ppm**
- **Dimming: off to full brightness in 16 steps; 66.66kHz PWM (pulse-width modulation).**

Instructions for using the Remote Switch Timer

The very first time the *Remote Switch Timer* is powered up, the backlighting will be off and the timer will be in the ON IN and OFF IN Once Only mode (Fig.5). Two lines will be displayed on the LCD, with the top line showing **ON IN"---:--"** and the lower line **OFF IN ---:--** The inverted commas in the first line show that the ON IN time can be changed using the Hours and Minutes Up/Down buttons.

The dashes mean that the timer is off. Note that three dashes are allocated for the hours position and two for the minutes. This represents three digits for the hours and two for the minutes. The settings can be up to 255h 59m. Note that if you want an hour value above 127, it's quicker to reach this by pressing the down button to count back from zero hours.

Pressing the Next button (S6) moves the inverted commas to the second line. The LCD then shows **OFF IN "---:--"** and the hours and minutes for this setting can again be adjusted using the up and down buttons.

Depending on the above setting, you also need to select whether the mains switch is initially on or off. That's done by pressing the ON or OFF button (Fig.7). Pressing the Set/Start pushbutton (S5) then starts the timing, with the colon between the hours and minutes digits flashing and the inverted commas off.

Pressing the Set/Start button again stops the timing, or you can do this to change the ON IN or OFF IN values. Note that timing will not begin unless the colon is flashing.

Changing the cycle

To check which cycle you are running or to change the cycle, press the Cycle button (S7). The current cycle will be displayed and this will initially be ON/OFF IN Once Only. Other selections are ON/OFF IN Repeat, ON/OFF AT Repeat and ON/OFF AT Once Only (Figs.8-10).

You can just view the setting, by pressing the Cycle button for up to 10s. Pressing it for longer than 10s lets you move to the alternative settings. After 10s, the cycle indicator will be shown and the unit will count down from 10 to 0. When zero is reached, the cycle changes to the next selection. It's just a matter of holding the Cycle button down until the required cycle is reached.

The hours and minutes settings for the ON/OFF AT cycle are achieved in exactly the same manner as for the ON/OFF IN cycle, with the Next pushbutton again used to select the OFF AT timer.

Adjust ppm correction

Pressing the Next button after OFF AT has been selected brings up the 'Adjust ppm' correction value on the top line and the real-time clock on the bottom line (Fig.11). A right arrow shows which line can be changed using the Hours and Minutes buttons. As before, pressing the Next button cycles through the selections.

The ppm setting is initially zero, but can be changed using either the Hours or Minute buttons to ±99 maximum. A positive value speeds up the clock, while a negative value slows it down. A 1ppm change represents about 2.6s in 30 days or about 1s every 11.5 days. The 99ppm maximum adjustment corresponds to 256s in 30 days or about 8.53s per day.

The real-time clock runs continuously and its time can only be changed in Set mode. The seconds are reset to zero each time the hours or minutes are changed, allowing the clock to be easily synchronised with another clock. Note that only the clock is shown in run mode, not the ppm crystal correction value.

In practice, it's all very straightforward and is far less complicated than it sounds. A few minutes spent playing with the buttons will familiarise you with the way it works.

What's remembered?

If you don't use the battery back-up, then the *Remote Switch Timer* will power off in a blackout or when you disconnect power. When power is restored, the timers will be at zero (showing dashes) and the clock will initially begin from zero (midnight). However, the cycle setting, backlight dimming level and crystal ppm correction value will all be restored to their values before power went off.

By contrast, with battery back-up, the clock and timers will continue to run and their settings will not change. In addition, the last ON or OFF setting required for the remote mains socket will be remembered and re-sent after a 3s delay when power is restored.

the base of the case using the label's self-adhesive backing.

Dataflex and Datapol labels are available from **www.blanklabels.com.au** and sample sheets are available on request to test in your printer – see panel.

Once the label is in position, the *Remote Switch Timer* PCB can be attached to the rear of the lid using tapped spacers and M3 × 5mm machine screws. M3 × 9mm spacers are used for the UB1 box, while M3 × 12mm spacers are used for the polycarbonate case so the LCD module sits inside the clear lid (this eliminates the need for a display cutout).

Alternatively, if you are using a PCB front-panel with the UB1 box, it's simply a matter of mounting the PCB on M3 × 9mm spacers.

DC socket and battery holder

An 8mm-diameter hole has to be drilled in the lefthand end of the

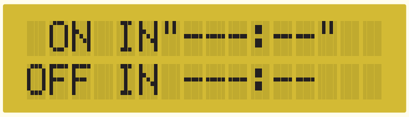


Fig.5: when first powered up, the unit is in ON IN and OFF IN Once Only mode. The inverted commas indicate that the ON IN time can be set using the Hours and Minutes buttons.

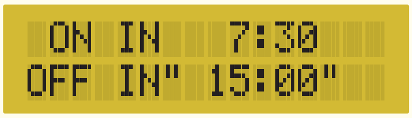


Fig.6: the unit has been programmed here to turn on in 7.5 hours and off after 15 hours. Pressing the Set/Start button starts the timers.

Fig.7: pressing the On or Off button sets the initial on/off state of the remote mains socket.

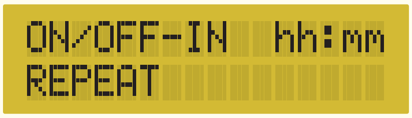


Fig.8: different settings (or modes) are selected by pressing and holding down the Cycle button. ON/OFF-IN Repeat mode has been selected here.

Fig.9: the ON/OFF-AT mode. Both Once Only and Repeat settings are available.

Fig.10: the unit has been programmed here to turn on and off at set times.

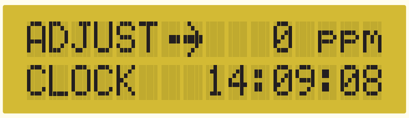


Fig.11: pressing the next button after OFF AT has been selected lets you adjust the clock and set the time.

case for the panel-mount DC socket. This can then be fitted in position and the wiring leads connected (the other ends of these wires terminate in 2-way header socket CON3). Be sure to connect these leads to the correct terminals on the DC socket (check with a DMM if necessary).

As stated, the back-up battery is optional. If you wish to use it, it's just a matter of connecting a 9V battery snap to CON5 and installing a 9V battery holder. Before soldering the battery snap leads, loop them through the adjacent strain relief holes. The holder can be secured to the base or to one side of the case using an M3 × 6mm machine screw and nut.

Remote control PCB

Before removing the remote's PCB module, the remote control mains socket (either from Jaycar or Altronics; see parts list) should be set to operate as described in the instructions. This will familiarise you with the way the units works and allow you to set the channel number and test its operation.

Once you've done that, the hand-held remote can be disassembled. The Jaycar remote has one screw located beneath the battery cover and when removed, the two halves of the remote case can be cracked open along the sides with a screwdriver. By contrast, the Altronics remote has two screws under the battery compartment lid and removing these allows you to split the case.

It's then just a matter of removing the remote PCB and connecting the leads from CON1, CON2 and CON4. CON1 is wired across the ON contacts for the selected channel, CON2 across the OFF contacts and CON4 to the UHF remote's supply rails. Figs.3 and 4 show the details.

On the Jaycar remote, it will be necessary to scrape away the solder masking from the rear of the PCB before soldering the connections. Once all the wires are in place, fit a cable tie around the four switch wires to prevent them from pulling away from the PCB. It's also a good idea to use neutral-cure silicone or hot melt glue to hold the wires in place.

The remote PCB can now be mounted on the base of the case. Both the Jaycar and Altronics remotes have two holes that can be used as mounting points, although the Jaycar unit's holes will need to be enlarged to 3mm. In each case, the unit can be mounted (copper side up) on 9mm tapped spacers and secured using M3 × 5mm machine screws.

Once it's in place, plug the various leads into the sockets on the back of the timer PCB and fasten the lid down. That's it – the unit is ready for use. The full instructions on driving it are in the accompanying panel.

Teach-In 2015

Discrete Linear Circuit Design

Part 10: Summing up

by Mike and Richard Tooley

Welcome to *Teach-In 2015*. This series is aimed at anyone wishing to develop a detailed understanding of linear discrete semiconductor devices and how they are used in a diverse range of circuits. We hope you will join us on this exciting voyage of discovery!

Each part of our *Teach-In 2015* series is devoted to a different aspect of discrete linear circuit design, such as modelling and simulation, measurement and testing, and noise and distortion. In last month's instalment, *Knowledge Base* took a detailed look at stability, thermal and over-current protection, while *Get Real* was devoted to the design and construction of a low-cost high-quality 10W power amplifier for use with previous *Get Real* circuits, allowing you to build your own good quality modular audio system.

Introduction

In this final part of *Teach-In 2015*, our *Discover* feature will be delving into to some of the practical aspects relating to measurement, adjustment and fault-finding on power amplifiers. *Knowledge Base* looks at power supplies in general, culminating with the design of a mains supply that can be used to provide power for all of our practical *Get Real* projects. *Get Real* brings the series to a conclusion when we describe the tests that we made on our high-quality 10W amplifier and reveal whether or not it met or exceeded our original design specification.

Knowledge base: Power supplies

The quality of the power supply has a significant impact on the amount of output power that can be realised by an amplifier in both the short and long term. Of paramount importance in the design of the power supply is its ability to maintain the rated output voltage under driven signal conditions. The current demand will increase with output power and, as a consequence, the supply rail voltages will fall. The amount by which the supply voltage falls under load is referred to as its 'load regulation', and it is usually quoted as a percentage:

$$\text{Percentage regulation} = \frac{V_{ol} - V_{fl}}{V_{ol}} \times 100$$

Where V_{ol} is the output voltage off-load and V_{fl} is the full-load output voltage. Typical values of regulation are in the range 5% to 10%. Values greater than 10% are likely to be problematic, while values of less than 4% may be difficult to achieve without some form of electronic voltage regulation.

It's worth illustrating this with an example. Let's assume that a power supply produces 20V when off-load and that the output falls to 18V when the supply is fully-loaded, delivering a current of 2A to an amplifier. The load voltage regulation is calculated as follows:

$$\text{Percentage regulation} = \frac{20-18}{20} \times 100 = 10\%$$

Another way of understanding the reduction of output voltage is as a result of the internal resistance of the power supply. A supply that can deliver very large load currents will have a small internal resistance, while one that can only deliver a small load current will have a relatively high value of internal resistance.

Using the figures that we've just quoted, the supply voltage falls by 2V (ie, 20V – 18V) when the load current increases from zero (off-load) to 2A (full-load). The supply thus exhibits an internal resistance of 2V/2A = 1Ω.

It is worth mentioning that, under normal no-load conditions (ie, when no signal is present) the power supply will still be delivering some current to the amplifier, but this will only be the bias current for the output stage along with supply current for the Class-A driver and pre-driver stages. In most amplifiers this will only be a few tens of mA rather than the much larger currents that are required when an amplifier is driven. It is also worth noting that appreciably larger values of supply current will be demanded when an amplifier is driving a low resistance load, thus 2Ω and 3Ω loads will require considerably more current than 4Ω, 8Ω or 15Ω loads.

When designing a power supply you will need to have a reliable estimate of the amount of current required by an amplifier. Let's assume that you are dealing with a 10W amplifier and a purely resistive 4Ω load. To deliver 10W of power to the load under sinusoidal conditions the amplifier will need to produce an undistorted output of around 6.3V RMS (or around 9V peak). Under these conditions the RMS current supplied to the load will be 1.6A. The average current supplied by each of the two supply rails will be about 63% of this, or about 1A from each rail. Thus, to produce 10W output we will need a symmetrical supply rated at 1A or more.

We would also need sufficient voltage from each rail in order to produce an undistorted output swing of at least $18V_{pk\text{-}pk}$. However, since the output devices cannot be driven into perfect saturation we will need to allow some additional headroom voltage. In practice, it is sensible to allow a minimum of 2V for each output transistor and, since there will also be a small voltage drop across the emitter resistors, the authors suggest a margin of at least 20% of the supply. This suggests that, for a 10W amplifier and a 4Ω load, we would require supply rail voltages of around ±15V in order to deliver an undistorted output voltage swing of $18V_{pk\text{-}pk}$ (recall that a significant amount of distortion will appear at the onset of clipping).

Mains transformer

The mains transformer is crucially important but, since this component

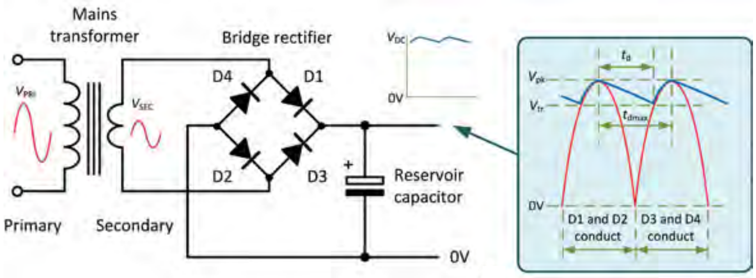


Fig.10.1. Basic arrangement of a full-wave bridge rectifier

is inevitably imperfect, its secondary output voltage will fall on-load and this will contribute to the sagging DC output voltage when a power supply is on-load. The voltage regulation of the power transformer needs to be kept as low as possible and, for an amplifier rated at more than 5W, should be less than about 12%. The mains transformer also needs to be appropriately rated in terms of secondary voltage and secondary current. The authors recommend using a component that is rated in VA (volt-amperes) at least double that of the output power of an amplifier. Thus, we would recommend a component rated at around 50VA for a 10W stereo (dual-channel) audio system. It would be even better if both amplifiers in a dual system had their own individual power supplies, but this is, of course, a more costly option since it will require the use of two separate power transformers.

Reservoir capacitors

The reservoir capacitors have the important role of 'holding up' the output voltage from the bridge rectifier. The capacitors will charge on each peak of the secondary input voltage (during which the respective rectifier diodes will be conducting) and then retain this charge when the secondary voltage falls (see Fig.10.1). The general rule of thumb is to use a capacitor, suitably rated in terms of working voltage and ripple current, with a value that is as large as possible within the physical constraints of the board on which it is mounted.

It is possible to obtain a rough 'ball park' value of the capacitance required by assuming that the capacitor has a maximum discharge time equivalent to the time for one half-cycle of the mains supply (recall that the bridge rectifier is providing full-wave rectification and so the 'ripple' frequency will be 100Hz, not 50Hz). The recommended value of capacitor can then be estimated from the relationship:

$$C = \frac{I_{max} \times t_{dmax}}{V_{pk} - V_{tr}}$$

Where I_{max} is the maximum load current, t_{dmax} is the maximum discharge time, V_{pk} and V_{tr} are the peak and trough voltages respectively (see Fig.10.1) and the DC output voltage (V_{DC}) is simply the average of these two. Let's take an example based on the reservoir capacitors that we might need for our 10W high-quality amplifier. Assume that we would not be prepared to tolerate a voltage fall of more than 1V on each supply rail. We should thus plan for a worst-case situation in which V_{pk} = 17V and V_{tr} = 16V (in other words, a maximum ripple voltage of $1V_{pk}$).

With a 50Hz supply, the value of t_{dmax} would be 10ms and the maximum load current will be around 1A. Hence:

$$C = \frac{1 \times 10 \times 10^{-3}}{17 - 16}\,\text{F} = 10\text{mF or } 10{,}000\mu\text{F}$$

The reservoir capacitors should have a maximum working voltage rating of at least 50% more than the expected DC voltage and with a ripple current that is at least 50% more than the maximum DC load current. Commonly available components rated at 25V or 35V with a ripple current rating of 2.5A would be suitable.

Dual-output power supply

Now let's put this into context by looking at the complete circuit of the dual-output power supply that we designed for use with the high-quality 10W amplifier described in last month's *Get Real*. This circuit was designed with symmetrical outputs to supply a nominal ±15V at a current of around 850mA, but in order to allow for some additional margin for other *Get Real* modules, we uprated this to 1.5A to provide a margin of about 500mA for a separate regulated supply. The complete circuit of the dual-output power supply is shown in Fig.10.2.

A 50VA transformer (T1) provides two individual secondary windings, each rated at 12V 2A. Full-wave rectification is provided by a bridge rectifier rated at a continuous 50V, 2A. The DC output from this arrangement is developed across C1 and C2, which act as the main reservoir capacitors for the two symmetrical output voltage rails.

The unloaded DC output voltage from the power supply is approximately ±17V, but as explained earlier, on load this will fall by a volt or so to approximately ±16V. In addition, a separate regulated 9V supply is provided for other *Get Real* modules via a three-terminal voltage regulator, IC1. This regulated output is rated for a total load current of up to 500mA.

Separate indicators are provided for each of the two voltage rails. Red LED (D1) indicates the presence of the positive nominal 15V supply, while a green LED (D2) indicates the presence of the nominal –15V supply. Fuses provide protection on the primary of the mains transformer (via F1 rated at 1A) and on the DC outputs (via F2 and F3, each rated at 2A). It should be noted that F1 should be a slow-blow (delay) fuse, while F2 and F3 are quick-blow types. The regulated output at 9V is short-circuit protected within IC1.

Take care with the construction of the power supply because high AC voltages are present on the primary side of T1. It is also necessary to ensure that an earth connection is provided to the frame of T1 and also to the common 0V rail. Construction should be fairly straightforward and we used point-to-point wiring inside a low-cost ABS enclosure with the output voltages accessible via screw-terminal connectors.

Components

Resistors

2 1kΩ 0.5W (R1, R2)

Capacitors

2 10,000µF 35V (C1, C2)
2 100nF (C3, C4)
1 220µF 35V (C5)

Semiconductors

1 50V 2A bridge rectifier
1 Red LED (D1)
1 Green LED (D2)
1 7809 regulator (IC1)

Miscellaneous

1 50VA transformer with two 12V 2A secondary windings
3 miniature fuse holders
2 2A quick blow fuses
1 1A slow-blow fuse

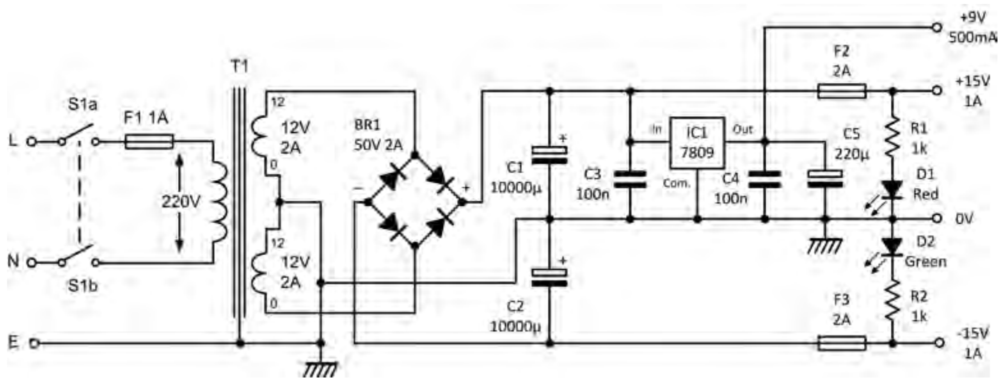


Fig.10.2. Complete circuit of our dual-output power supply

Discover: Measurement, adjustment and fault finding

In order to carry out simple tests and adjustments on linear circuits you will need to have access to a selection of basic test equipment, including a low-cost digital multi-meter and a means of generating and displaying signal waveforms. For checking power amplifiers it is also useful to have access to a power meter, but this is not essential as long as you can provide a suitably rated load (see *EPE*, July 2015).

Real versus virtual test instruments

In the March 2015 issue of *EPE* we discussed the use of software-based virtual test instruments where computer sound cards provide the analogue-to-digital and digital-to-analogue conversion. As previously discussed, this approach has some limitations, but it is nonetheless cost-effective and offers an excellent starting point for people with a limited budget. Measuring voltage gain, frequency response, and examining distortion can all be easily done. However, meaningful distortion and noise measurements require more specialised (and consequently more expensive) test equipment. This can either be computer based with a dedicated external high-speed ADC and DAC or can make use of stand-alone instruments. Alternatively, good quality second-hand instruments are available from a number of suppliers, including several of our regular *EPE* advertisers.

Distortion measurements (THD with or without noise) can be made using low-cost software (see Fig.10.4) but care is needed to ensure that indications are accurate. More accurate results are usually obtained with external PC-controlled signal sources and ADC converters rather than internal mass produced PC sound cards. If an internal sound card is to be used then this should be set for the highest (24-bit) resolution and a conversion rate of 96kHz, or more. Where reliable distortion measurements are required, measurements can be made using high-end analysis software such as Yoshimasa Electronics DSSF3 (see Fig.10.5).

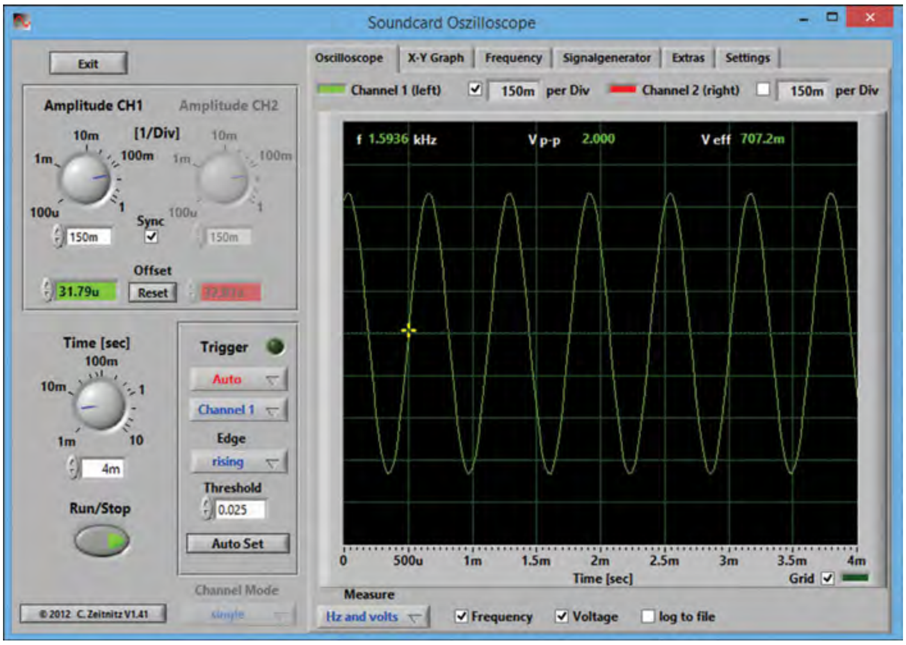


Fig.10.3. Virtual sound-card based test instruments provide a cost-effective method of carrying out basic tests and measurements on a wide range of linear circuits. Note how frequency, pk-pk and RMS values are calculated and automatically displayed on the virtual oscilloscope screen

Testing and adjustment

Fig.10.6 shows various test, measurement and adjustment points on a typical audio amplifier. A typical test procedure would involve first checking the positive and negative supply rails and then performing the symmetry and bias adjustment along the lines discussed in Part 8 of *Teach-In 2015*. Note that, since there will be some interaction between adjustments it may be necessary to repeat the procedure several times for optimum results.

At this point it's worth mentioning that the circuit shown in Fig.10.6 uses a form of feedback that we've not previously discussed. This is known as 'bootstrap feedback' and its name arises from the fact that, when the voltage at the emitter of TR4 increases the feedback sends this back to produce a corresponding increase in the voltage at the base of TR2. Thus it can be said that the output stage 'pulls itself up by the bootstraps'.

Bootstrap feedback has the effect of raising the effective load resistance seen by the driver stage, TR1. As a result, the voltage gain of the stage is increased (recall that the voltage gain of a common-emitter amplifier is directly proportional to the value of collector load resistance, see page 41 of *EPE*, March 2015). It is also worth noting that this type of feedback (which results in an increase in gain of the driver stage) is positive rather than negative, but there is no risk of oscillation as the overall voltage gain provided by the two cascaded emitter followers in the output stage will be less than 1.

Fig.10.7 shows another common circuit arrangement which uses a more sophisticated method of deriving the output stage bias. In this arrangement it can often be useful to pre-set the bias voltage (to just less

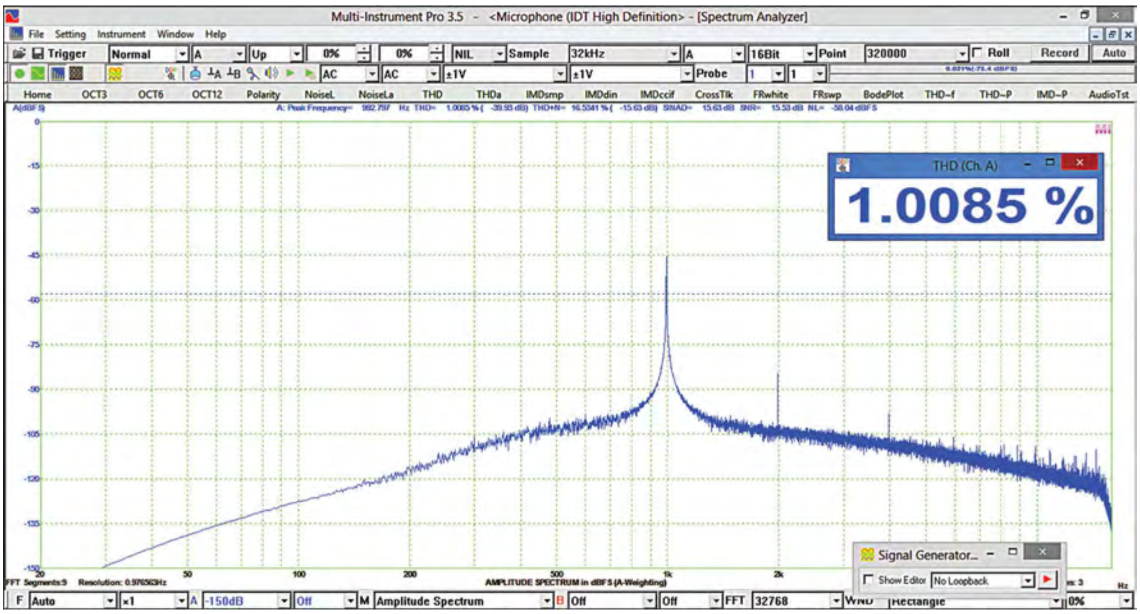


Fig.10.4. Virtins Multi Instrument software includes THD and noise measurement

than 2.4V in this case) before making the bias and symmetry adjustments. The performance of this arrangement is very similar to that of the output stage shown in Fig.10.6 but note that we have a slightly reduced device count by using integrated Darlington pairs rather than individual transistors.

Fig.10.8 shows the typical arrangement of a 50W amplifier incorporating over-current protection. As explained in Part 9 of *Teach-In 2015*, TR3 and TR4 (NPN and PNP devices respectively) sense the voltage appearing across the output stage emitter resistors. When these voltages exceed 0.6V, or so, the respective device conducts heavily and clamps the bias voltage. The symmetry (0V balance) and bias adjustment of this circuit is otherwise identical to that of the circuit shown in Fig.10.6.

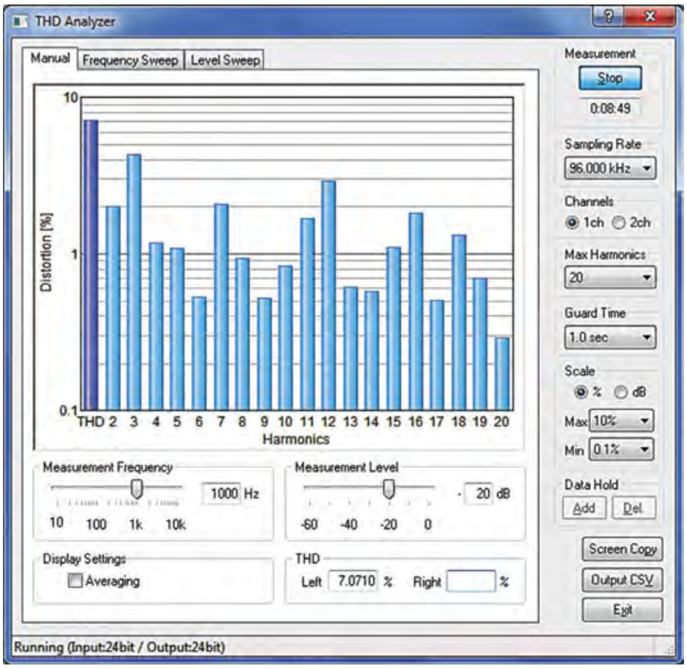


Fig.10.5. DSSF3's THD analyser measuring the distortion present on a 1kHz sinewave signal produced by a low-cost PC sound card. Note the indicated THD of a little more than 7% and the relatively high values of some of the high-order harmonic components

Waveform measurements

Having checked the supply rails, bias and symmetry of a power amplifier, the next stage involves applying signals and checking gain, output power and distortion. All of these measurements will require the use of a signal source and a means of displaying waveforms. A sinewave signal can be derived from an audio frequency signal generator (either real or virtual) or from a waveform generator. Note that the synthesised sinewave produced by a virtual signal source or from a waveform generator will not usually be as pure as that available from a dedicated audio frequency signal generator. Typical distortion figures (THD+noise) from a waveform generator might be as high as 2%, while that of a good quality low-distortion audio signal generator will generally only be a tiny fraction of 1%.

Fig.10.9 shows typical waveforms obtained at the output of a power amplifier when on load and with a sinewave input. Fig.10.9a shows the undistorted output waveform, while Fig.10.9b shows the symmetrical clipping, which will occur when the amplifier is being over-driven. This waveform can also occur if both of the power rail voltages are abnormally low, indicating a fault in the power supply.

Fig.10.9c and Fig.10.9d show waveforms that are clipped at their positive and negative extremes respectively. These waveforms usually result from incorrect symmetry adjustment, but this condition can usually be resolved fairly easily. The fault may also occur if one or other (but not both) of the power rail voltages is abnormally low. In such cases it will be necessary to check the negative supply voltage.

Fig.10.9e arises when there is high-frequency oscillation superimposed on the output waveform. This may arise under certain load conditions and so it is worth checking the output when on and off load to see if the problem is sensitive to the load. A properly designed amplifier should not exhibit this fault condition. If the condition prevails it is also worth checking that screened cables are used at the input, that the screening is properly earthed, and that the input wiring is kept well away from the output wiring and cabling to the loudspeaker.

In Fig.10.9f, the output signal shows bursts of oscillation that may occur at certain points on the output waveform. As with Fig.10.9e, this indicates a problem with the stability of the amplifier at high frequencies and may also be affected by load conditions. Once again, this is a condition that should not arise in a properly designed amplifier (see *Teach-In 2015* Part 9).

Fig.10.9g shows, on a slightly different time scale, the effect of inadequate reservoir/smoothing in the power supply. The unwanted ripple on the supply rails will appear as a 100Hz buzz in a loudspeaker. Note that this is not the same as 50Hz hum that might be introduced due to inadequate screening or earthing at the input. If the problem is persistent it might be worth investigating and/or upgrading the reservoir capacitors in the DC power supply.

Finally, the semiconductor devices used in the output stage of a power amplifier are prone to failure due to the relatively high voltages and currents at which they operate. When one or more of the supply fuses blow it is important to check both output transistors for short circuits between collector and emitter.

A useful clue as to what has been happening in the output stage can be obtained by examining the emitter resistors. If these are running very hot (or if they show signs of burning) this usually indicates a failed device. If you do need to replace one or both of the output transistors it can also be worth replacing the emitter resistors at the same time. Following replacement it will also be necessary to carry out

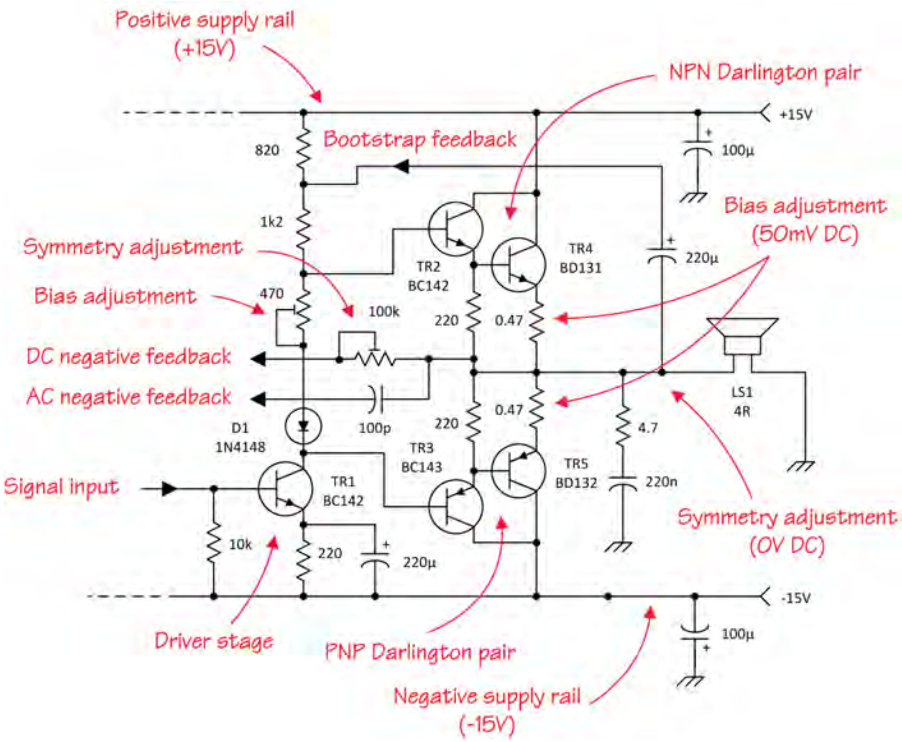


Fig.10.6. Adjustment and test points on a typical amplifier

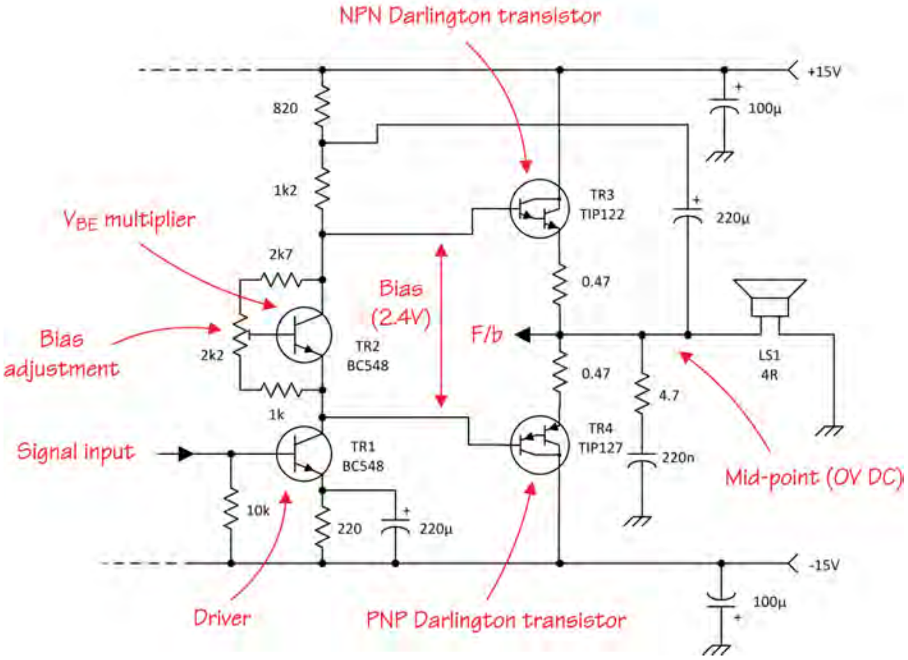


Fig.10.7. Bias adjustment based on a V_{BE} multiplier

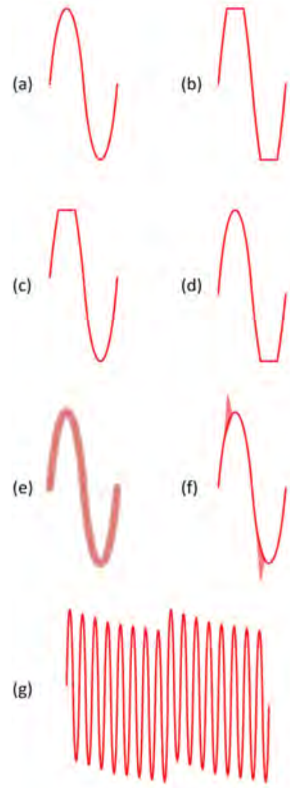


Fig.10.9. Typical waveforms with various fault conditions present

the bias and symmetry adjustments, as described earlier. If the correct bias cannot be obtained and the emitter resistors continue to run hot then this may indicate a fault in the driver stage.

Get Real: Testing the high-performance 10W audio power amplifier

Our final *Get Real* project was designed to satisfy the need for a simple, low-cost power amplifier that can be used with the other modules in this series to realise a complete modular audio system. Our aim was that of providing a simple design that could outperform comparable designs based on integrated circuits with a total build-cost of well under £10 (excluding the printed circuit board).

We carried out some detailed tests and measurements both at the simulation, pre-prototype and final prototype stages. Table 10.1 summarises the most important results and shows how closely we came to meeting the original design specification.

Voltage gain

The voltage gain was measured at 1kHz and was slightly more than 20dB (equivalent to a voltage gain of 10). This was exactly as required and agreed with the value obtained by simulation.

Frequency response

Fig.10.10 shows the Tina Design Suite settings used to measure the frequency response of the simulated version of the 10W amplifier. Note that we set the Start and Stop frequencies at 1Hz and 100kHz respectively and that the High and Low display settings have been set to 30dB and 0dB respectively. Fig.10.11 shows the frequency response graph obtained from the settings shown in Fig.10.10. The response is substantially flat and extends from below 10Hz to around 20kHz. We measured the frequency response of the final prototype in a test lab and the resulting response curve is shown in Fig.10.12. Note how this agrees very closely with the predicted and simulated frequency response.

Distortion

At the outset we were very keen to ensure that the amplifier produced negligible distortion at maximum rated power. On test, the total harmonic distortion (THD) was found to be 0.4% at rated output and better than 0.5% for power levels ranging from 1W to 12W (measured with a 4Ω load at 1kHz). This was not quite as good a result as that obtained with our pre-prototype version which, with careful adjustment, was capable of producing a mere 0.05% THD at rated output. However, in comparison with modern integrated circuit class-AB amplifiers, the performance was felt to be reasonably good and very much less than STA450, TDA2004 and the ever-popular

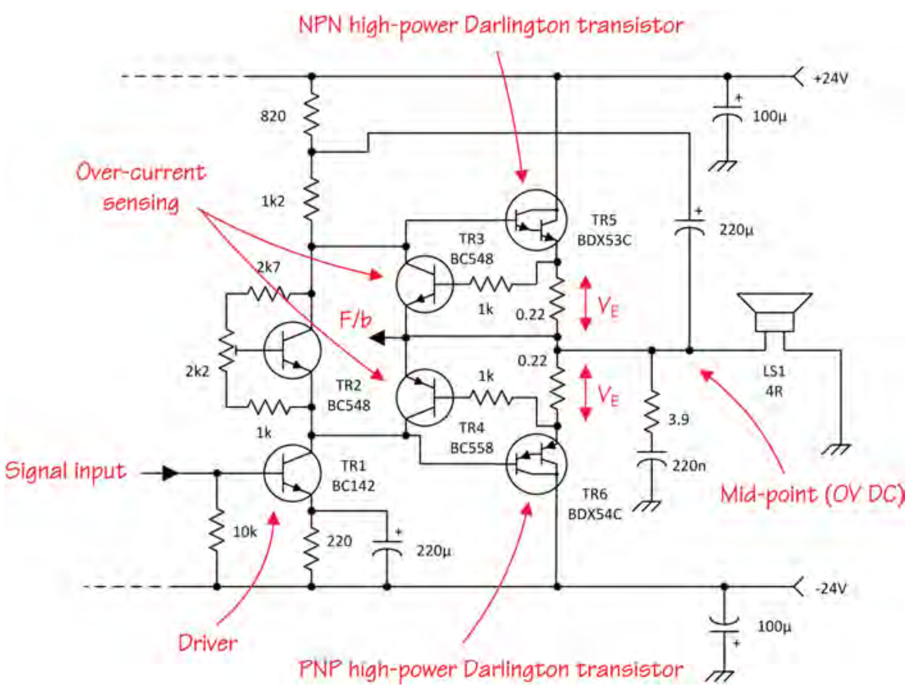


Fig.10.8. A 50W amplifier with over-current protection

Table 10.1. Summary of design and actual measured parameters for the high-quality 10W audio amplifier

Parameter	Design specification	Simulated performance	Measured performance (test lab)
Voltage gain	10 (approx.)	10.5	10
Frequency response	Better than 10Hz to 20kHz at –1dB	3Hz to 30kHz at –3dB	5Hz to 35kHz at -3dB
Input impedance	50kΩ (approx.)	88kΩ	75kΩ
Output power	10W into 4Ω at 1kHz at less than 1% THD	10W into 4Ω at 1kHz	10W into 4Ω at 1kHz at less than 1% THD
Phase shift	0° at 1kHz	0° at 1kHz	0° at 1kHz
Distortion	Better than 0.5% THD at 5W output into 4Ω	Not measured	0.4% THD at 10W output into 4Ω
Supply	50mA (no signal), 1A (max.) with nominal ±15V DC supply	65mA (no signal) rising to 849mA with 10W output at 1kHz into 4Ω	53mA (no signal) rising to 850mA with 10W output at 1kHz into 4Ω

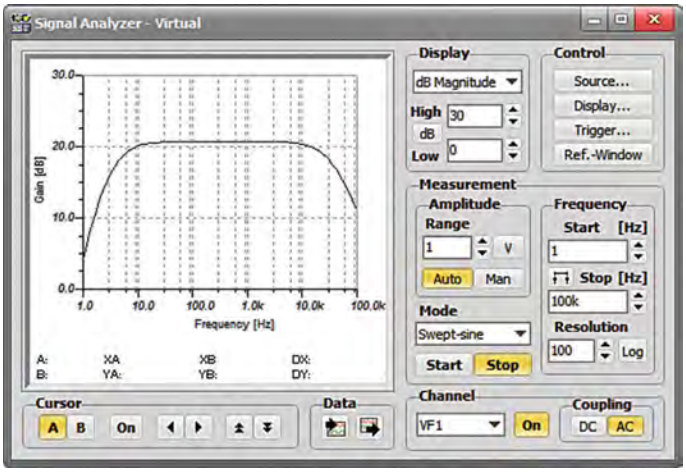


Fig.10.10. Tina Design Suite settings for measuring the frequency response of the 10W amplifier

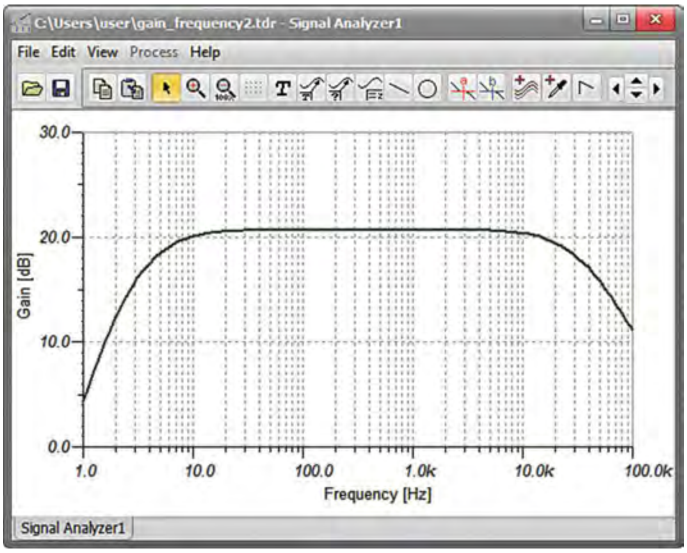


Fig.10.11. Frequency response graph obtained from the settings shown in Fig.10.10

TDA2003 chip. When operating from a 14.4V supply, this latter device will produce 6W in a 4Ω load and10W into 2Ω, but at a rather worrying THD of 10%.

Thermal considerations

We carried out a number of thermal checks on our design with the 8.3°C/W heatsinks specified. At a sustained 10W output into a 4Ω load and at an ambient temperature of 20°C the heatsink surface temperature in the immediate proximity of TR6 and TR8 reached 65°C after 20 minutes of operation. At a sustained 5W output and at an ambient temperature of 20°C the heatsink temperature measured at the same point reached 46°C after 20 minutes operation. With only 1W continuous output the heatsink temperature failed to reach 30°C with just free air circulation. The results of these tests are shown in Fig.10.13.

Conclusion

The tests on our high-quality 10W amplifier bring *Teach-In 2015* to a conclusion. We very much hope that you've enjoyed the series and that you managed to find time to build and test some of our *Get Real* projects. If you did, you should have gained a basic understanding of analogue circuits and how to use modelling and simulation to optimise your own circuit designs. Analogue electronics is fascinating and there's a whole world of 'linear' out there waiting for you to explore!

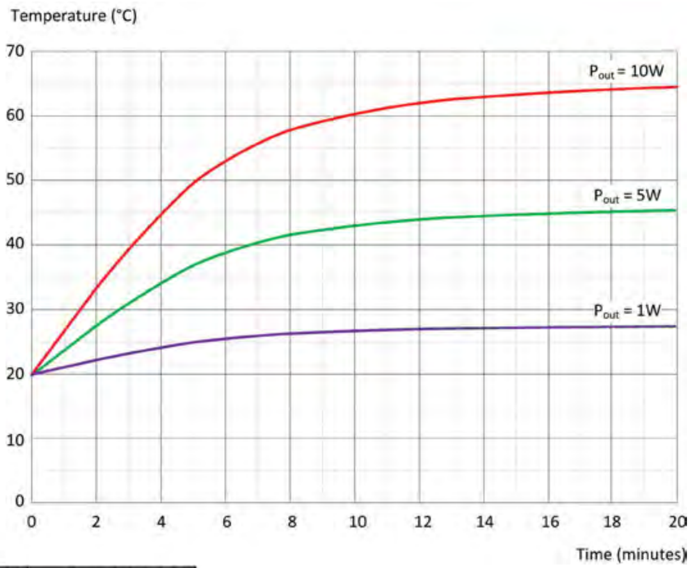


Fig.10.13. Results of the thermal measurements (the tests were carried out with the amplifier placed in the open air with free-air circulation and at an ambient temperature of 20°C)

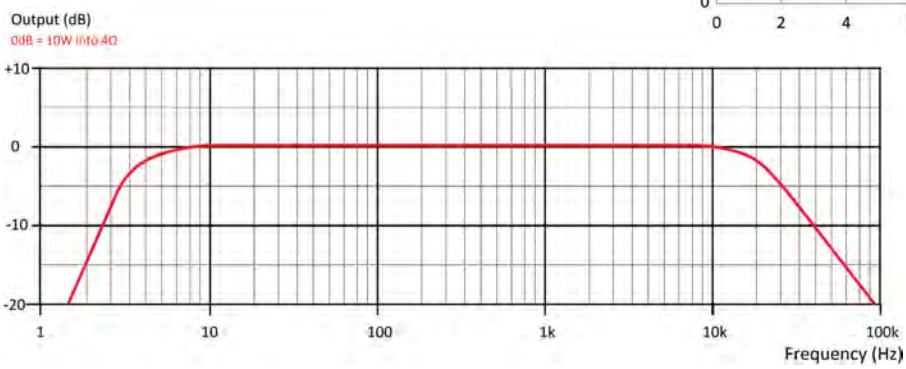


Fig.10.12. Measured frequency response of the 10W amplifier

Teach-In 2015 index

NET WORK

by Alan Winstanley

Fifty shades of grey icons

WELCOME to this month's *Net Work*, the column that keeps readers posted with current online trends in Internet and associated networking technologies.

Last month, I focussed on July's launch of Windows 10, Microsoft's latest effort to dominate the desktop, and it was not long before I found myself helping a new Windows 10 Internet user who was now struggling with email problems. The 'Get Windows 10' popup having done its job, the computer owner had taken the plunge and updated their Windows 7 PC accordingly. This gave me an early opportunity to get to grips with Microsoft's latest user interface and web browser in the field – albeit under a certain degree of duress!

I duly logged in remotely to my first Windows 10 desktop. To its credit, Microsoft Windows 10's designers have done a very fair job of shoe-horning it onto the PC, but among other problems it was found that Office Outlook would no longer send email. However, the system could *receive* POP3 mail as normal and the new Edge web browser surfed the net, which proved that the LAN was running and the PC could reach out onto the Internet.

Looking around, I was again struck by how flat and featureless the design of Windows 10 is compared to Windows 7. The UI has evolved from the Windows 8 'Metro' touch-screen style of coloured tiles that casual users seem to crave: presumably all they want to do is flick around Facebook, post a few photos, send the odd email or run an app or two. Power users, who intuitively want to dig deeper, will find some aspects of Windows 10 a hindrance. I disliked the flat, over-simplified gif-style UI spawned by current trends, and I particularly struggled with Windows 10's navigation: too many isolated, borderless icons in various shade of light grey dotted around, which only change colour when you 'mouse' over them. There were no visual cues like 3D buttons, drop shadows or recognisable slider controls to be seen – just coloured rectangles, all jostling for space with those poorly-contrasting 'Minimise' or 'Close' grey icons dotted around that do anything but jump out at you. I found myself casting around for buttons that were ghosted against the glaring white screen.

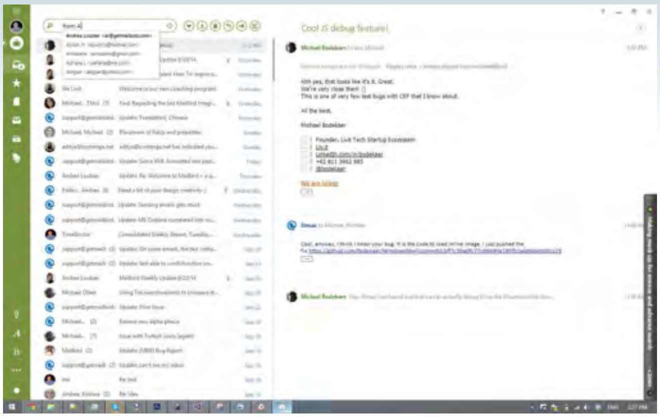
Back to the email problem: the failure of outgoing mail suggested that Outlook's SMTP settings should be checked first. Email authentication was also examined to confirm mail was being submitted to port 587 as it should be. This form of ID check, with a username and login, ensures that legitimate users of a domain name can submit email to their corresponding mail server, and that spammers cannot impersonate the domain as the sender. For some reason, I found the port settings had defaulted to port 25, which is blocked by many hosts. This was corrected to port 587 and with the authentication settings also enabled everything now checked out 'on paper' – but email was stubbornly stuck in the Out tray and it refused to budge!

Next up was the antivirus package, AVG 2015, which has a plethora of mail scanning options and it too was found to be scanning outbound mail on port 25 by default. This was reverted to 587, but mail still would not go. Rather nervously, disabling AVG altogether for a minute made no difference either and outgoing mail was still stuck in the Out tray. This was turning into a very puzzling problem, and being confronted with a new user interface did not help.

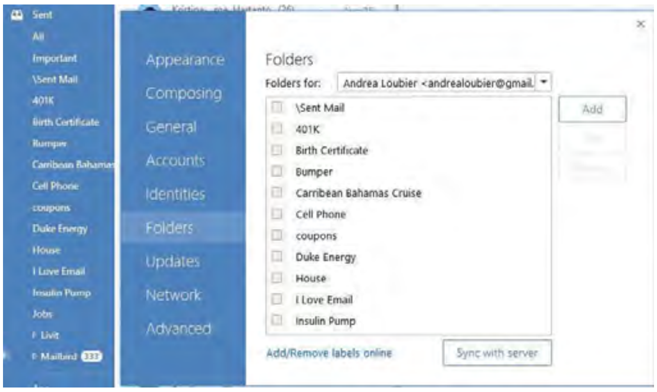
Command prompt

An IT tech support agent then suggested that Windows 10 might be the culprit (!), and it was recommended that System File Checker (SFC) was run, so I would be using Windows 10 'in anger' for the first time. A seasoned Windows user would type `cmd` in Search or go `Start/Run/cmd` to open a familiar DOS box (command prompt) and run SFC that way, but there would be no such luck in this Windows 10 setup. With pressure mounting, the only way it seemed was to use the Windows 10 'Search' function to look for `cmd` and a minute elapsed while the disk was scanned. Then some bland Windows 10 tiles opened up, referencing `cmd,` but which I found virtually impossible to comprehend. I decided to search for **cmd.exe** my way, by finding the System 32 folder in Windows and (right-click) Run as Administrator followed by `>sfc/scannow` from the command prompt. With scanning finally under way, I left the PC to clatter away to itself for a while.

Windows 10 builds on Windows 8 and has a flat two-dimensional style that some Windows PC users may find a hindrance



Mailbird is a well-regarded, standalone email program with a modern 2D interface. The software can be colour-themed and the menu bar (left-hand side) rotated



The minimalist folder view in Mailbird typifies the style of present-generation software

After scanning the Windows 10 file system, nothing apparently untoward was found, but then I remembered the advice to close and re-open Outlook, and – lo and behold – outbound mail suddenly went on its way and the problem was resolved! Whatever was wrong with the Windows 10 setup had been cured, so some quick email tests followed and everything was well once again.

Many will cite operating system problems like these as good reasons to migrate email to the cloud, and foist email management onto someone else. However, many experienced Internet users still prefer to manage email for themselves, but finding a non-Office Outlook email program for everyday use is becoming a major headache. Windows Live Mail (Windows 7 or higher) is a candidate but the list of other contenders is quite short, and traditionalists will face a culture shock when confronted by the latest generations of email and cloud applications that all use the minimal UI style first seen in Google apps and touch screens.

A modern email PC program such as **Mailbird** is one of a better breed of programs notable for a range of plugins (Dropbox, Whatsapp, Twitter, Facebook, Evernote and more) which considerably increases its versatility. It has the same flat style that many seasoned users will probably find lacking. A free version of Mailbird can be downloaded from **www.getmailbird.com** and the Pro demo times out after 30 days. As Microsoft and Adobe users know all too well, software subscription models are now all the rage and for those wanting to upgrade from the free edition Mailbird Pro costs $12 a year or $45 for a lifetime once-only charge.

How do you manage your email in today's cloud-driven world? Drop me a line at the usual address and share your experiences and recommendations with other readers.

An inside job?

In the September issue I described some phone line and broadband problems that might have struck a chord with British Telecom (BT) customers. I had gone through a phase of various line faults and outages lasting several months when BT Openreach, the telecom contractor, installed some phone lines for a construction site nearby. Local residential users, including the writer, were plagued by crossed lines, no dial tone, no broadband and various permutations of all three. As fast as one fault was fixed it seemed another one was introduced by BT Openreach engineers, who stuck doggedly to the mantra that faults should be reported and it will take up to five days to fix them. Even when they had just disconnected my line in error (which I 'reported' by shouting to the likely-looking culprit found working up a telegraph pole nearby), I had to start the fault-reporting process all over again and thus the pantomime continued until normal service was eventually restored after many weeks of disruption.

These telephone and VDSL problems resulted in several fraught calls being made to BT's overseas call centres, where phone faults like these are handled. Soon afterwards, I started to receive a multitude of international phone calls in quick succession. An associate in the same town who had likewise reported broadband faults to BT was having the same experience – overseas calls were now being received on a private telephone line from people reading off a script who claimed to be 'Microsoft Windows' or who wanted to talk about my 'BT Internet' connection.

Of course, I knew this was a scam, but others have been stung by these fraudsters, who try to tap remotely into your PC and create a string of bogus faults or error messages. They then extort hard cash out of their hapless victims to fix these non-existent faults. The crooks mercilessly target vulnerable or elderly computer users and I can well imagine innocent people falling for these con tricks.

By now I was receiving several such calls every day. At the same time, the *Daily Mail* columnist Dominic Lawson wrote that, soon after reporting a problem with his BT broadband via the BT overseas call centre, he was contacted multiple times by overseas fraudsters claiming he had a broadband problem and offering to log in and fix them. The implication was that BT phone numbers were maybe leaking out from BT overseas call centres and into the hands of crooks. This seemed too much of a coincidence and so I took the matter up with BT Security.

I handed over my account details with a list of some suspicious international phone numbers that had called me repeatedly. BT Security analysed my account activity and spreadsheets of incoming calls were then produced. The possibility of having, as BT put it, 'one bad apple' at their call centre could not be ruled out and the potential risk of legitimate UK phone numbers finding their ways into the hands of criminals this way has not yet been eliminated. At the time of writing, BT stated that certain overseas call centre agents were currently being interviewed as part of their enquiries and the investigation was ongoing. Meantime, innocent people are still receiving these bogus calls even today, so ensure you spread the word and warn friends and family to be on their guard against these scammers.

Dangerous deliveries

Next, a timely reminder about the real risks faced by those buying or selling items via the Internet. The ubiquitous eBay is the first port of call for those wanting to trade via the web, and the usually positive experience is fuelled by eBay's relentless drive to ensure vendors work hard to earn their 5-star detailed seller ratings.

Buying at arm's length can be fine for many items, but the combination of eBay and PayPal fees, the high cost of postage or the need to handle valuable goods or dispose of (say) bulky furniture locally has given rise to rival online outlets, including classified ad site Gumtree, at (**www.gumtree.com**). This service continues to evolve and offers a more relaxed approach than eBay, with private sellers listing goods for free. It is a basic way of putting local people in touch with each other, and apart from hard goods, Gumtree also offers jobs, property and more for sale. Another method of trading is to find a local Facebook group, as there is a fair chance one exists near your town or village. Again, listing items for sale is free.

Classified ad sites present their own real-world security risks, including the fact that potential buyers can remain semi-anonymous. One-to-one 'classified' cash transactions like these pose plenty of personal risks, and a lot of common sense should be exercised by users, especially if handling attractive goods such as iPhones or MacBooks. To cite some recent criminal cases, an unsuspecting user reportedly downloaded a job application from Gumtree, but it was claimed the document contained a virus that captured her bank login details: a popup window required the user to change her password, which she did, after which the laptop locked up and thieves proceeded to log in remotely and empty her bank account.

Something more sinister befell an innocent Gumtree user who sought to buy an iPhone being advertised locally for over £400. He was reportedly tricked into driving to what turned out to be a campsite, where the seller was waiting for him and he was nearly robbed of all the cash. Realising it was a stitch-up, he managed to escape in his car barely in the nick of time. The reverse situation has also happened, with sellers of desirable goods being robbed at knifepoint by 'buyers' who turn up on spec, and there has been at least one report of a fatal attack when a seller was robbed of a valuable laptop. Thus, the modern-day web has brought with it some old-world dangers, and traders need to be vigilant and exercise everyday caution and common sense in their dealings even more.

Next month, I'll look at enhancing home security in the form of installing an IP camera, together with a neat idea that turns a flat-screen HDMI TV or PC monitor into a useful, Android-based Wi-Fi computer. You can email the author at: **alan@epemag.demon.co.uk**

Practically Speaking

Robert Penfold looks at the Techniques of Actually Doing it!

Circuit diagrams and symbols

EVERY published electronic project comes complete with a circuit diagram. It is not actually essential to have a circuit diagram if full details for constructing the device are provided, and neither is it necessary to have the ability to follow one. Being realistic about things though, the ability to read a circuit diagram is something that any electronics enthusiast should strive to master sooner rather than later. It is a prerequisite for understanding how circuits work. Also, the circuit diagram is usually the first port of call if some aspect of the electronic side of construction is unclear, or does not seem to be quite right. Some cross checking here will usually clarify matters.

Eventually, most constructors tend to 'do their own thing', and rely less on the construction information provided in articles. In some cases there will be no construction details to rely on. There are numerous circuits published in magazines, books, and on the Internet, with no construction information at all. Before too long, most constructors try to build some of these. The ability to understand circuit diagrams then becomes essential rather than an optional extra.

Symbolism

Learning to read a circuit diagram is not particularly difficult, and the obvious starting point is to learn the more common circuit symbols. A selection of circuit symbols and the names of the components that they represent are shown in Fig.1. With anything that involves symbols, it is as well to bear in mind that there are likely to be stylistic differences from one source to another. While most of the symbols in published circuits will not be exact matches for those shown in Fig.1, for the most part they will closely resemble them.

The rectangular resistor symbols are the 'proper' ones, but are not universally accepted. Although they are not the current British standard, the old zigzag symbols are still used a great deal in the UK. The zigzag symbols are, of course, used for the circuit diagrams in *EPE*. Both sets of resistor symbols are included in Fig.1. There was once a move towards using the rectangular symbol for any component having two leads. The letter in the marking beside the symbol indicated the type of component that the symbol represented. As a couple of examples, 'R2' would be a resistor, and 'L3' would be an inductor. This system made it easy to produce circuit diagrams using the crude computer based drawing systems of the time, but it also made circuit diagrams relatively difficult to read. This method has been largely phased out, but you could still encounter circuit diagrams of this type. In fact, you are almost certain to encounter them if you search the Internet for circuits.

Circuits published on the Internet can be a bit difficult to interpret, because there seems to be no international standard for

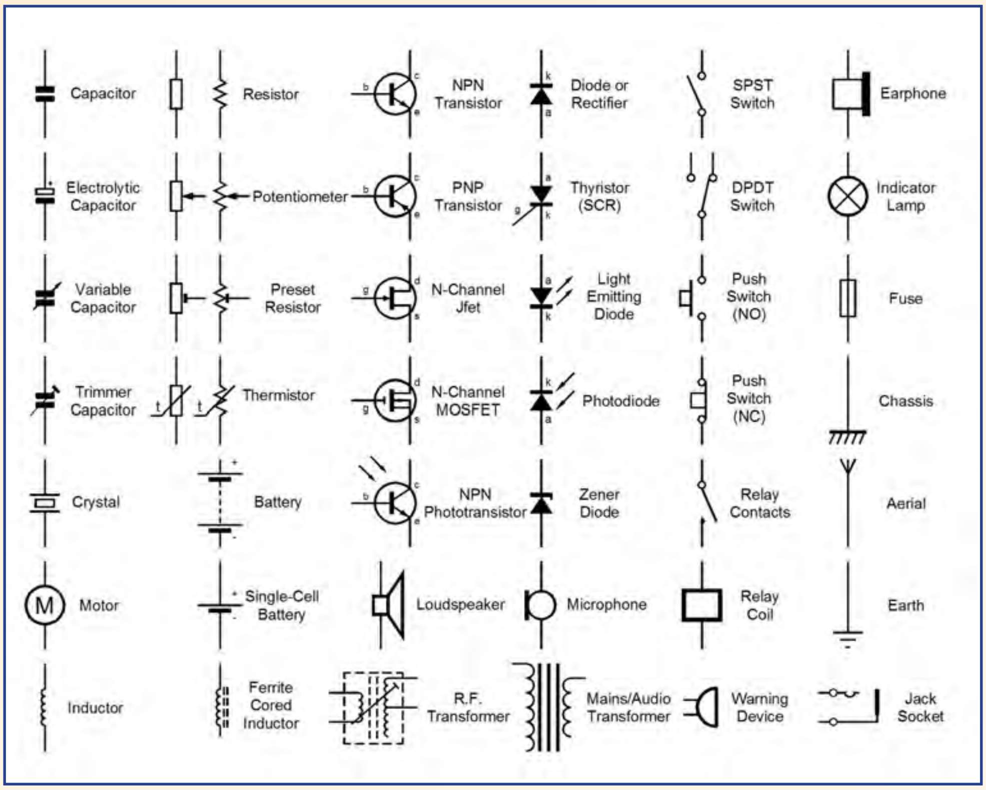


Fig.1. Circuit symbols for a wide range of components – bear in mind that there will be stylistic differences in real-world circuit diagrams, in addition to some variations from one country to another

Table 1: Component identification letters

Letter(s)	Component
B	Battery
BY	Battery
C	Capacitor (any fixed value type)
CH	Chassis
CRT	Cathode ray tube
CSR	Thyristor or triac (controlled silicon rectifier)
D	Diode (any type, including rectifiers, photodiodes, and LEDs)
E	Earth
FL	Filter (usually a ceramic, crystal, or mechanical type)
FS	Fuse
JK	Jack socket (any type)
IC	Integrated circuit (also U)
IFT	Intermediate frequency transformer
L	Inductor
LP	Lamp (neon or filament, but not LED)
LS	Loudspeaker
M	Motor
ME	Meter
Mic	Microphone
PCC	Photo conductive cell (a photoresistor such as a cadmium sulphide cell)
PL	Plug (any type)
Q	Transistor (also Tr)
R	Resistor (fixed value)
RL	Relay (coil or contacts)
RV	Potentiometer or variable resistor
S	Switch
SK	Socket (any type, but JK is often used for jack types)
SW	Switch
T	Transformer (any type including RF)
TC	Trimmer capacitor (preset variable capacitor)
Th	Thermistor
TL	Earphone or headphones
Tr	Transistor (also Q)
TR	Transistor
U	Integrated circuit (also IC)
V	Valve (any type except CRT)
VC	Variable capacitor
VR	Variable resistor or potentiometer
WD	Warning device (buzzer, bell)
X	Crystal

circuit symbols. In most cases, the symbols are the same or quite close to the British standards and there are no problems. In American circuits, for example, a capacitor has one straight line and one curved line instead of two straight lines. With electrolytic and other polarised capacitors the curved line can be used to indicate the '–' terminal. Polarised capacitors normally have '+' and/or '–' markings included on circuit diagrams, which should help to avoid confusion. Anyway, whichever type of symbol is used, a capacitor is still very obviously a capacitor, and where appropriate, the polarity should not be in doubt.

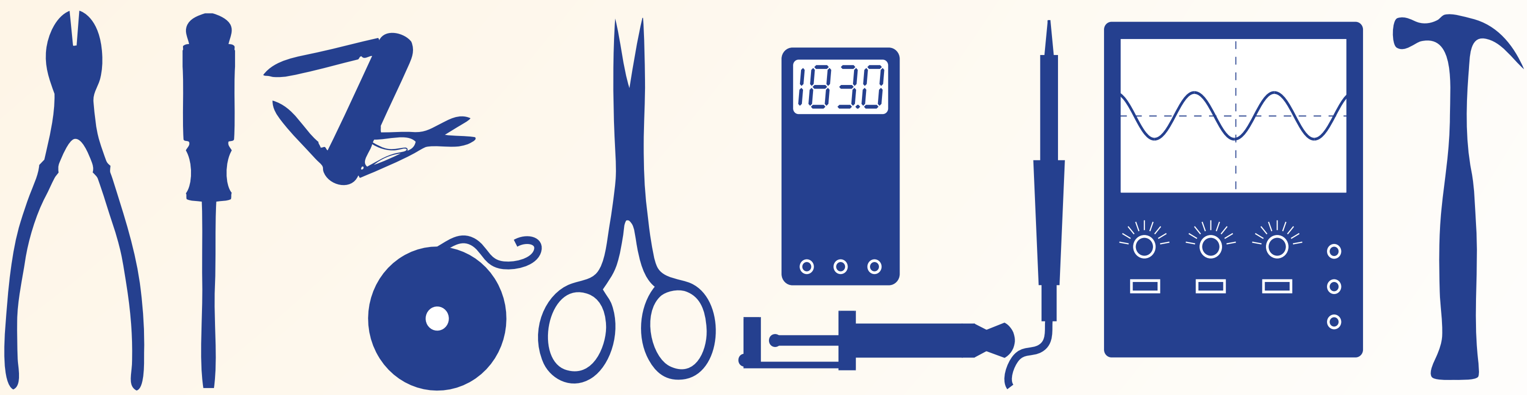
In the world of semiconductors, there can be marked differences in the symbols from one country to another. This can be something simple such as a circle added around a diode symbol, or the circle being omitted from a transistor symbol. In other cases, the differences might be more radical. The obvious way around the problem is to look at the component number, and rely on the letter or letters in the component number to tell you the type of component. This can also be useful when first learning to read circuit diagrams. The component numbers should come to the rescue if you forget what component one of the symbols represents. Table 1 is a list of component identification letters for all the common components.

With some components there is more than one method of identification in common use. In particular, there are three common methods of marking transistor symbols. In the UK, the component number is usually preceded by 'TR' or 'Tr', but elsewhere the letter 'Q' is often used. A component identification number for a semiconductor is followed by a type number rather than a value. If all else fails, looking up the semiconductor type number in a catalogue or on the Internet should make it clear whether the device in question is a transistor, triac, thyristor, or whatever. Similarly, if a component value is given as (say) '470pF', its value is in picofarads and it must be a capacitor.

No integrated circuit symbol is included in Fig.1, but the vast majority of these are simply represented by a rectangle, labelled with a pin number at each point where a lead emanates from the rectangle. Some integrated circuits have special circuit symbols, and this mainly applies to the basic logic types. Fig.2 shows the special integrated circuit symbols. With the simpler logic elements there can be more than one element per integrated circuit. If, for example, IC1 has four sections, these would be labelled as IC1a, IC1b, IC1c and IC1d on the circuit diagram. Amplifiers are represented by a triangle, and in the case of operational amplifiers (op amps) the two inputs are identified by '+' (non-inverting) and '–' (inverting) signs.

Crossing the line

Thin lines are used to represent the connections from one component to the next. Connections often run



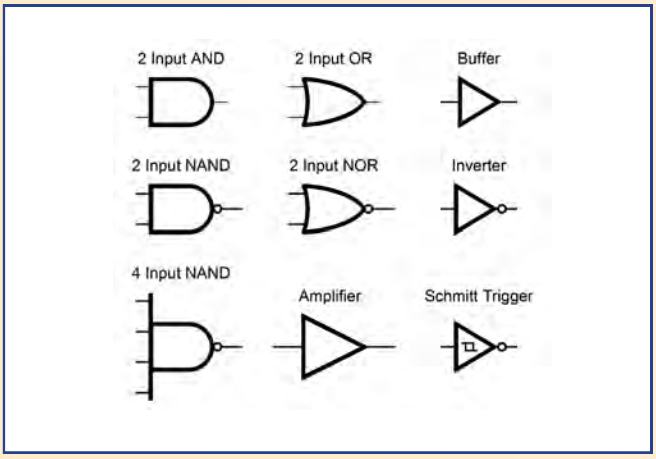


Fig.2. Most integrated circuits are simply represented by a rectangle, but amplifiers and basic logic elements have special symbols. It should be noted that there are often two or more gates/inverters per device, and that several of the relevant symbols might be needed in order to fully represent one integrated circuit

from component to component, perhaps connecting more than a dozen components together. The supply lines are the best example of this, and in a typical circuit most of the components will connect to at least one of the supply rails. There is no real problem in representing complex wiring on circuit diagrams, but in most cases there is no way of avoiding some lines crossing other lines. To avoid confusion, a dot is used where two lines meet and join, and no dot is used where lines cross without any connection being made.

Many years ago the convention was to have one wire loop over the other at points where there were crossovers with no connections. You might still encounter this method, but it is no longer part of the UK standard. The dummy circuit of Fig.3 helps to explain how things operate. In some countries the power rails are not included on circuits. Instead, relevant lines are terminated in arrowheads, and labels are used to indicate which supply rail each line connects to.

Theory into practice

With a little practice it is easy to see how everything is joined together on a circuit diagram, but translating a circuit diagram into a working project is less straightforward. First you need to know how each terminal of a component on the circuit diagram equates to its real world counterpart. This should not be too difficult for someone who has some experience of building electronic projects, and is reasonably familiar with the common components.

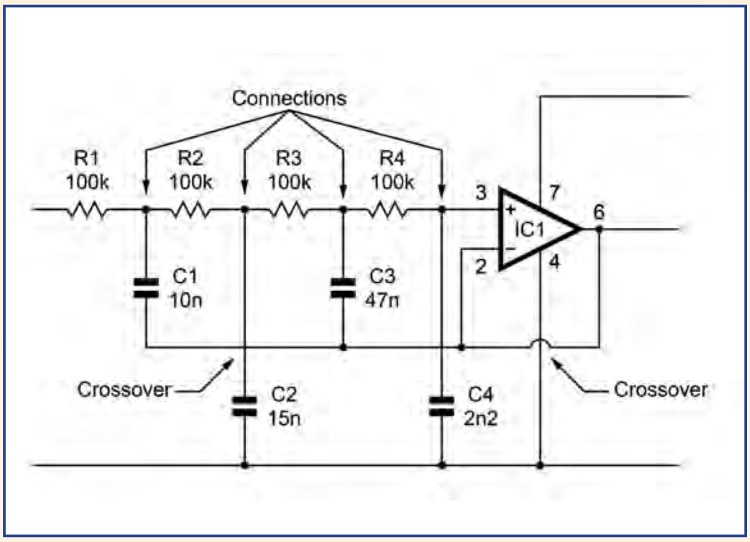


Fig.3. A dot is used to indicate that two intersecting wires are connected together. The absence of a dot, or one wire looping over another, indicates that the wires cross without any connection being made

Resistors and non-polarised capacitors have only two terminals, and it does not matter which way around they are connected. Polarised capacitors such as electrolytic types must be connected the right way around. The positive terminal is usually marked with a plus sign on circuits, and the polarity is marked with plus and (or) minus signs on the actual components, so there is no excuse for getting it wrong.

Transistors come in a variety of shapes and sizes, and devices that have the same encapsulation do not necessarily have the same leadout configuration. Consequently, it is only possible to identify the terminals of an unfamiliar device with the aid of the relevant leadout diagram. Electronic component catalogues usually have a section that provides leadout details for all the stocked devices. There is a vast amount of semiconductor data available on the Internet, and any of the popular search engines will almost instantly locate details for practically any transistor. Remember that convention is for transistor leadout diagrams to be base views. In other words, they show devices viewed looking at the side from which the leads emanate.

Most of the integrated circuits used in electronic projects have DIL (dual inline) encapsulations, and the pin numbering always runs counter clockwise from pin 1 (Fig.4). It does not matter whether a DIL component has 4 pins, 40 pins, or anything in between: the basic numbering system is the same. Pin 1 can be indicated by a notch at

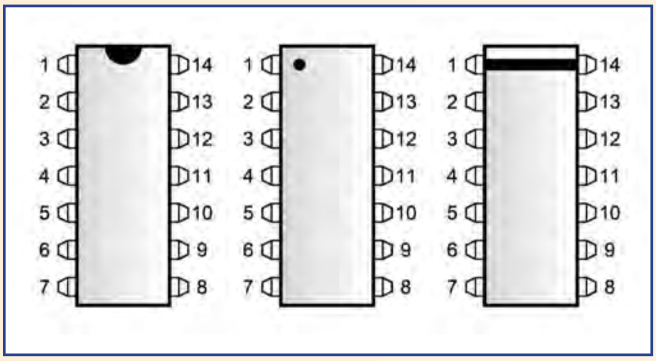


Fig.4. The three methods of indicating the position of pin 1 on a DIL integrated circuit. In practice, it is common for a chip to have two or even all three of these methods used

the appropriate end of the encapsulation, a dot or a bar next to pin 1, or any combination of these. With devices that have something other than a DIL encapsulation it is necessary to resort to component catalogues or the Internet to pair pin numbers on the circuit diagram with pins on the actual component.

Bear in mind that the convention for integrated circuit pin diagrams is for the components to be shown from above. In other words, the devices are shown with the pins pointing away from you, which is the opposite of the convention for transistors leadout diagrams. Even where a device has a transistor-style case and leadout wires, unless stated otherwise, the leadout diagram should be regarded as a top view.

Potentiometers

Fig.5 shows how the potentiometer circuit symbol relates to a rotary potentiometer, and identifies

the clockwise (CW) and counter clockwise terminals. This operates as one would probably expect, which is not always the case with the slider type. With these it is necessary to refer to the manufacturer's data, or to make some resistance checks using a multimeter.

One slightly awkward aspect when using a potentiometer is determining which way around the two track terminals should be connected. Sometimes 'CW' and 'CCW' markings are included on circuit diagrams, but without these there is no easy way of telling the correct method of connection. In the case of any sort of volume or level control, the CCW tag connects to the earth rail and the input signal is fed to the CW terminal. In other applications it is necessary to have some technical knowledge, or to use the 'suck it and see' method. The control will work 'backwards' if the track connections are the wrong way around.

Switches, sockets, and relays are relatively simple components, but it as well not to jump to conclusions when wiring them into a circuit. The obvious method of connection is not necessarily the right one. Some of these components have pin numbers or other useful connection information marked on the component itself. It is otherwise a matter of referring to the manufacturer's or retailer's literature for guidance, or simply make some continuity checks with a multimeter in order to sort things out.

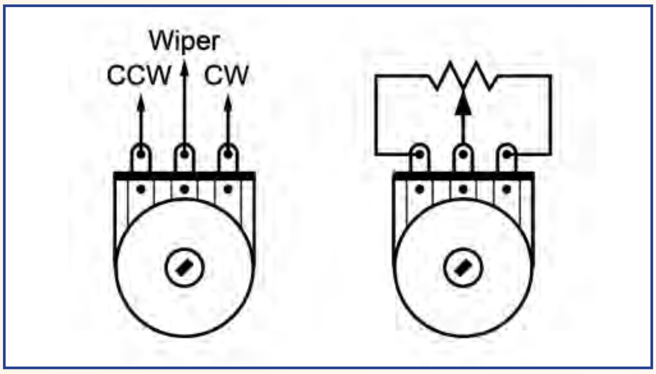


Fig.5. Rear view of rotary potentiometers identifying the three tags. If one terminal of a potentiometer connects to the earth rail, it is almost certain to be the counter-clockwise (CCW) terminal

CIRCUIT SURGERY

REGULAR CLINIC

BY IAN BELL

Analogue switches – Part 1

USER ***cjay*** posted the following question on the *EPE Chat Zone* forum: 'This may be a long shot… but does anyone know a source for a tiny SOT363 analogue SPDT IC called 'BL1551'? I have a transceiver that uses them for audio path switching and one has gone faulty. So far, the manufacturer has been unresponsive when asked for spares and I can only find them in China on AliExpress, which steadfastly refuses to let me open an account; a European source would be most useful. I'm sure there will be equivalents out there.'

The usefulness of the forum (and helpfulness of its contributors) was illustrated by a quick reply from user ***gordon*** suggesting the TS5A3159DBVR and ***cjay*** reported a successful repair about a week later. So we do not have a specific problem to solve from this post, but it is worth taking a look at analogue switches in general – their characteristics and use. This month, we will look at the fundamentals of the circuitry used to implement these switches. This will help with understanding their data-sheet parameters and circuit performance, something that, in general, may be necessary when trying to identify a suitable alternative for any type of device. Next month, we will look at circuit data sheet parameters and design aspects.

The term 'analogue switch' usually refers to an electronic equivalent to a mechanical switch or relay. Like relays, they are switched using electrical rather than mechanical or manual means, but they are implemented with semiconductor technology and have no moving parts. The term usually refers to devices intended for use in low-level signal applications, such as audio, video and instrumentation, rather than power switching. Thus, they are different from solid-state relays (SSRs), which are also semiconductor-based electronic switches. SSRs are intended for power switching and are often implemented using triacs or similar devices for the switching, typically with optically isolated control inputs. Analogue switches are usually implemented using FETs for switching, with directly controlled inputs.

Ideally, a signal passing through an 'on' switch will be exactly the same on both sides; however, this is not the case for real devices – they have resistance and other non-ideal characteristics, which tend to attenuate the signal, add noise and distortion and limit bandwidth. Electronic analogue switches tend to be much less ideal than mechanical ones, but their advantages of small size, low power, ease of control and fast switching, can outweigh their non-ideal characteristics in many situations.

The FET as a switch

The same basic circuit arrangement can be used to switch both digital and analogue signals. Electronic on/off switches are readily implemented in the same technology as CMOS logic and within digital circuits provide an alternative to standard logic gates for implementing some functions, particularly applications such as signal routing, bus switching, multiplexing and data selection. Thus, the first readily available analogue switch IC – now, about 45 years old – was probably the 4016 'quad bilateral switch' from the 4000 series of digital CMOS devices. An improved switch, the 4066, became available a little later. Devices of this type are still available – Texas Instruments describes its currently available CD4016B as 'Rev. C'. Despite the 4000 series being a logic family, analogue use of the switches was promoted on the datasheet and many designs over the years have used these chips for switching analogue signals. The 4016 and 4066 both contain four switches with individual control inputs. The 4066 has lower and less variable 'on-resistance'. Today, there are many more analogue switch chips to choose from, which offer better performance than the 4000 series originals.

As already indicated, FET transistors can behave like electronically controlled on/off switches. A single MOSFET transistor can be used this way, as shown in Fig.1. Here the MOSFET is shown with four terminals rather the three (gate, source and drain) that may be more familiar. The fourth terminal is labelled 'body' in Fig.1, but it can also be referred to as the 'bulk' or 'substrate' connection. It represents the silicon into which the transistor is formed. Voltages on the body silicon affect transistor operation, but in many cases, particularly in discrete transistors, the body and source are shorted within the device structure. However, this does not have to be done, particularly in integrated circuit designs, where there are many situations where the body needs to be connected separately from the source.

Symmetry

The body voltage has to ensure that the PN junctions between both the source and drain, and the bulk/substrate silicon in which the transistor is formed are always reverse biased. The most common arrangement is for the body connection of an NMOS transistor to be connected to the lowest voltage in the circuit (ground or negative supply) and the body connection of a PMOS transistor to be connected to the highest voltage (positive supply). With a separate body connection, and an appropriate device structure, the MOSFET is symmetrical and source and drain can be swapped. This is a requirement for providing a general-purpose switch function, which should function exactly the same irrespective of which way round the terminals are connected. In cases where the transistor is symmetrical we can designate the source and drain according to convenience, or to the orientation of circuit voltages we are dealing with.

The circuit in Fig.1 is very straightforward, but unfortunately the transistor switches off when the voltage being switched gets close to the control voltage. At least one terminal (source or drain) must have a voltage difference with the gate that is greater than the device's threshold (switch-on) voltage (V_T). This is because if the gate-channel voltage falls below V_T at

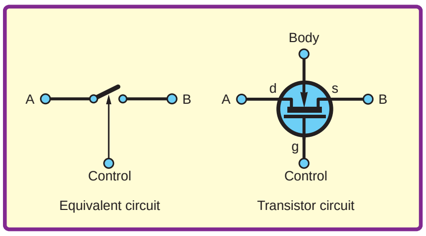


Fig.1. The MOS transistor as a switch

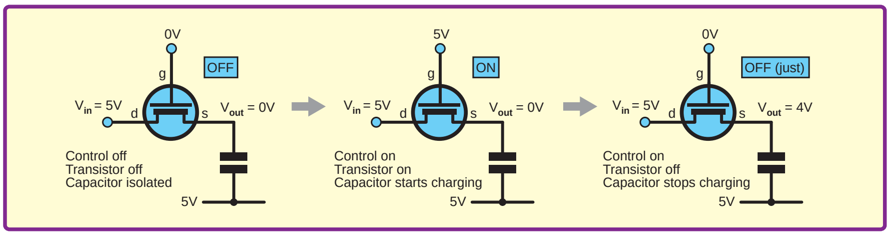


Fig.2. Capacitor charging via an NMOS switch

any point then the device will turn off. (The channel is the conductive path between source and drain when the device is on.) This limits the range of voltages that can be passed through the switch when it is on.

Restricted range

The problem with restricted voltage range is illustrated for an NMOS transistor using the circuit in Fig.2. Here the switch is used to connect an input voltage to a capacitor. If the switch was ideal then the capacitor would charge/discharge to the input voltage when the switch was closed, whatever input the voltage (within the limits of the components). This scenario is common because analogue switches are used explicitly to sample voltages onto capacitors (sample and hold circuits) and all real circuits will contain some capacitance that will have to charge/discharge when closing a switch shifts the circuit voltage.

In the circuit in Fig.2 the output of the switch transistor is connected to a capacitance that must be charged or discharged via the transistor when it is on. The first part of Fig.2 shows an off NMOS switch with the input (V_{in}) connected to +5V (assumed to be the supply voltage) and the output (V_{out}) connected to a capacitor currently at 0V (ground voltage). The transistor is then switched on by switching the gate voltage from 0V to 5V, and the capacitor starts to charge towards 5V via the transistor (second part of Fig.2). However, as the capacitor voltage increases, the transistor's gate-source voltage decreases and eventually the transistor will start to turn off. This happens when the gate-source voltage reaches the transistor's threshold voltage, which is assumed to be 1V in Fig.2. This means that for the situation shown in Fig.2, the output will only reach 4V (third part of Fig.2). If the input voltage is 4V or lower then the capacitor will charge to the input voltage.

For a PMOS transistor we have a similar situation, except that it is switched on with 0V at the gate and off by 5V (assuming the same supply as in Fig.2). An input voltage of 5V would charge the capacitor to 5V – the switch would work fine in this situation. Unfortunately, for voltages below the threshold voltage the PMOS switch will not function correctly. If the capacitor started at 5V it would only discharge to 1V (assuming a 1V threshold again) if the input voltage was 0V.

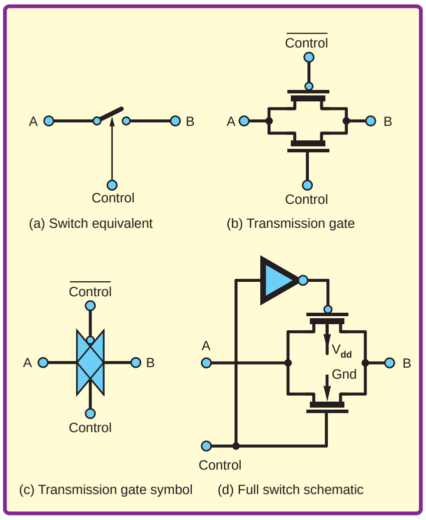


Fig.3. CMOS bilateral switch

Two transistors

The voltage range problem of the single MOS switch can be overcome by using two parallel MOS transistors, one PMOS and one NMOS, as shown in Fig.3d. This arrangement is called a 'bilateral switch' or 'analogue switch'. At least one of the transistors is on when control is on for all in/out voltages within the supply range. The basic configuration of the two transistors in parallel (Fig.3b) is equivalent to a simple switch (Fig.3a) and is known as a 'transmission gate'. The schematic symbol for a transmission gate is shown in Fig.3c. To make an analogue switch with a single control input an inverter is required to provide a complementary control signal to the two transistors, as shown in Fig.3d. The schematic symbol for a full analogue switch (Fig.3d) is usually similar to Fig.3a. The transmission gate symbol is encountered in logic schematics and detailed schematics of switch circuits.

Now that we have a viable basic switch (single-pole, single-thrown – SPST) it is straightforward to form electronic equivalents of other mechanical switches, such as single-pole, double-throw (SPDT) and rotary switches. The circuit in Fig.4 shows an SPDT analogue switch. Multiple-pole switches are implemented by replicating the switches and using a common control signal.

Monolithic MOSFET

We can use a SPICE simulation to verify that, unlike single-transistor switches, the bilateral switch is able to function with the full supply range of input voltages. The circuit in Fig.5 can be used for this purpose. Before looking at the results we need to cover some points about how this simulation is set up. The circuit uses a four-terminal MOSFET symbol in line with our previous discussion on this. The four terminal devices are selected using `nmos4` and `pmos4` when placing components, rather than `nmos` or `pmos`.

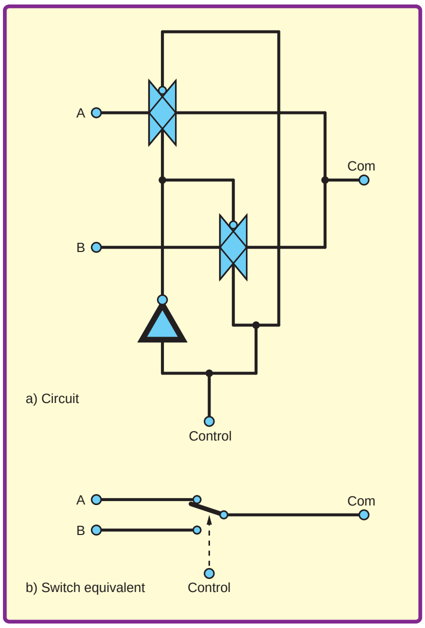


Fig.4. Schematic for a single-pole double-throw (SPDT) analogue switch

Unlike the three-terminal devices, which allow you to select a real discrete device from the library, right clicking a four terminal MOSFET symbol causes a 'Monolithic MOSFET' window to appear. This dialogue requests information on the physical dimensions of the device – we are in the realm of integrated circuits rather than designing with discrete components. The minimum information required is a device model name and the width and length of the transistor. For our purposes, the specific width and length are not particularly critical, but we will use a device that is significantly wider than it is long as this gives relatively low resistance.

We need to supply a device model; again we can use a minimal approach for this simulation. Hence, we need to specify the following device parameters: `KP`, which is a gain value, `VT0`, which is the threshold voltage and `Lambda`, which models the effect of drain-source voltage on drain current (channel-length modulation). Values of `KP` = 100µA/V², `VT0` = 1V (NMOS), `VT0` = –1V (PMOS) and `Lambda` = 0.01 suffice for a generic device in our simulation and can be seen in the `.model` directives on the schematic (use the `.op` command button to add them).

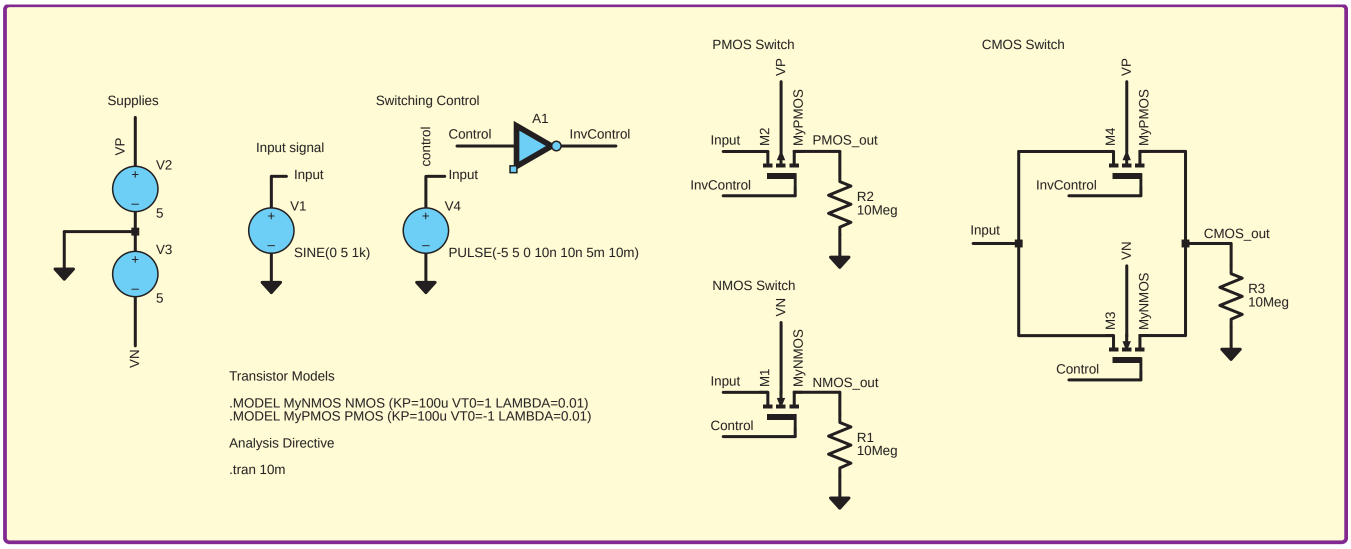


Fig.5. Schematic for LTSpice simulation of MOSFET-based switches

Inverter model

In order to produce the complementary control signal for the PMOS transistors, an LTSpice special function inverter is used. LTSpice is fundamentally an analogue simulator, but it does provide some proprietary special functions (not part of 'standard' SPICE) to model idealised basic digital gates and flip-flops. These can be useful when simulating analogue circuits with digital interfaces and similar mixed-circuit scenarios. The gates have default logic levels of 0V and 1V, but our circuit switches the control voltage between –5V and +5V, so we need to change the logic levels. To do this we right-click the inverter symbol (A1) on the schematic and enter the text `Vhigh=5 Vlow=-5` into the value field of the Component Attribute Editor dialog which appears.

In the simulation, all three versions of the switch are driven from the same ideal 1kHz, 5V peak sinewave source. The other side of each switch is connected to an individual 10MΩ resistor, representing a high impedance load, which might occur, for example, when switching the input to an amplifier. The switches are toggled on and off every 5ms using a pulse source.

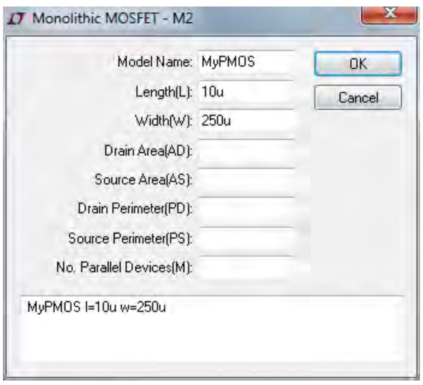


Fig.6. Monolithic MOSFET parameters dialogue in LTSpice

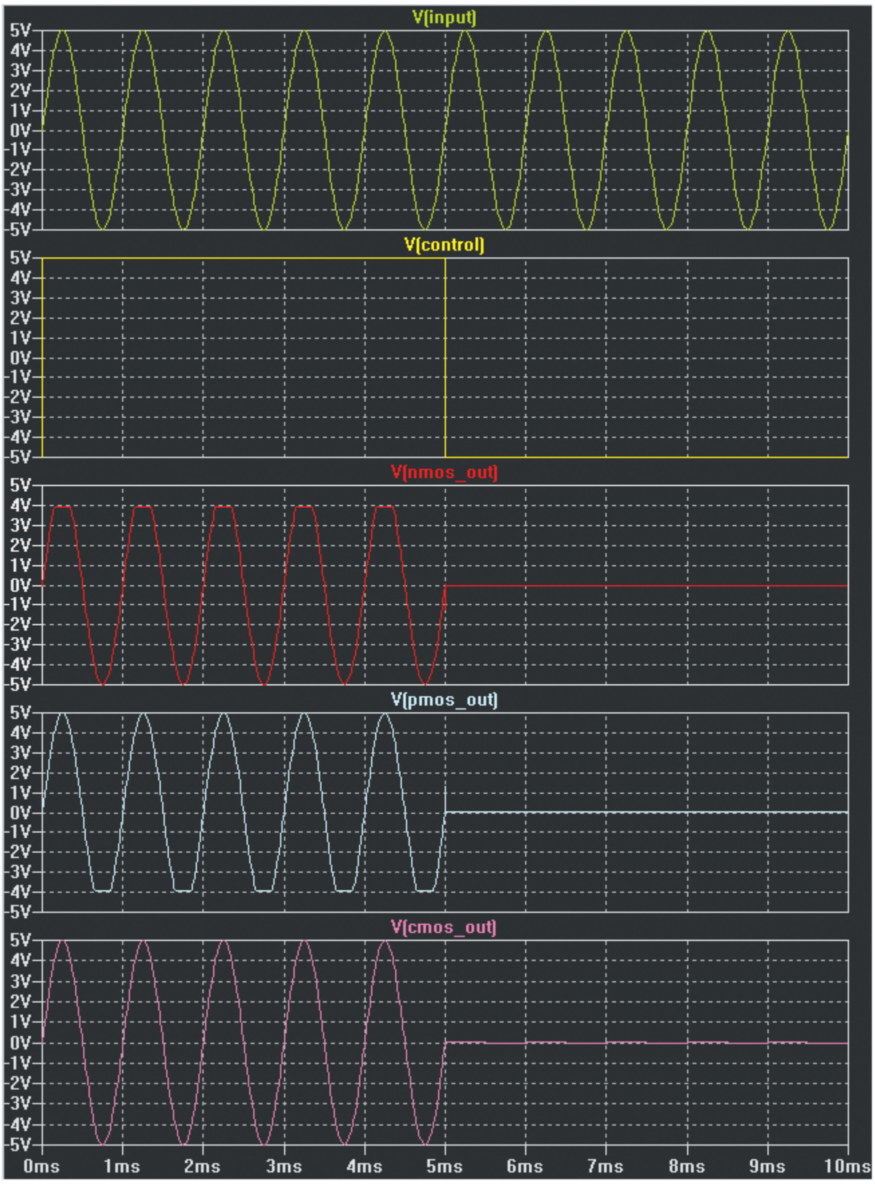


Fig.7. Simulation of circuits shown in Fig.5. Note that the NMOS and PMOS switches do not pass signals over the full supply voltage range

Results

The results of the simulation (one switch cycle) are shown in Fig.7, in which all voltage scales are the same (–5V to +5V). The top trace is the input sinewave and the second trace is the control signal. The bottom three traces show the outputs from the switches (NMOS, PMOS, bilateral/CMOS respectively). It can be seen that only

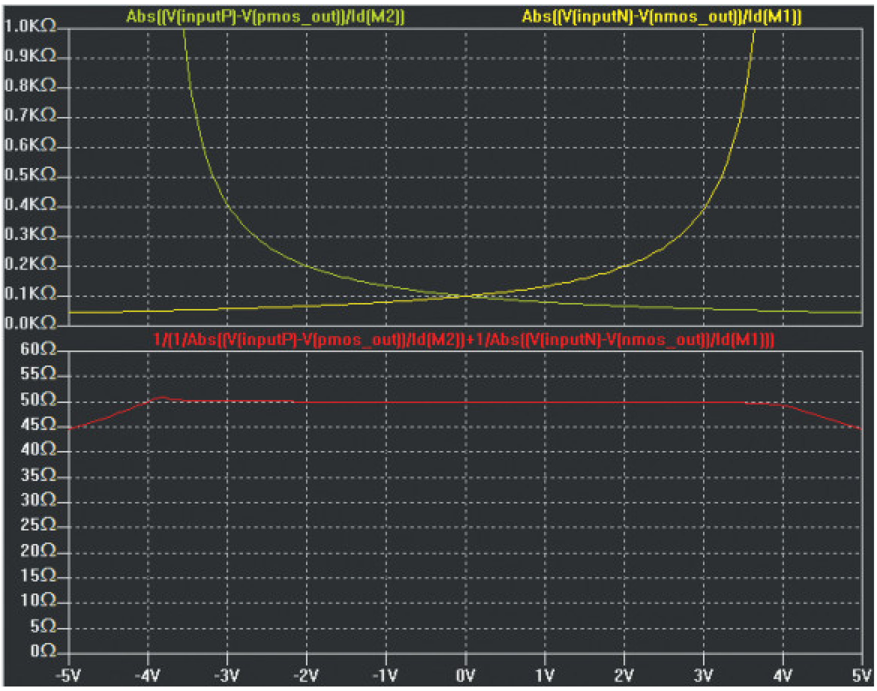


Fig.8. Variation of switch resistance with input voltage using a simulation based on Fig.5. Upper plot shows resistance of single transistor NMOS (yellow) and PMOS (green) switches. Lower plot shows parallel resistance of the two complentary transistors based on the values from the upper plot

the two-transistor switch allows the input to pass without being degraded. The NMOS transistor switches off when the voltage being switched is within V_T of the positive supply – that is, above +4V. The PMOS transistor switches off when the voltage being switched is within V_T of the negative supply, that is, below –4V (recall, the model sets the magnitude of V_T to 1V for both transistors). The NMOS and PMOS switches result in clipped waveforms.

R_{ON} flatness

Earlier, it was mentioned that analogue switches are non-ideal in terms of their resistance when on (R_{ON}). This resistance means that signals are attenuated as they pass through the switch, but the resistance is also not constant with signal level, that is, the switches are non-linear and will therefore cause distortion. Single transistor switches show the greatest amount of R_{ON} variation – their resistance increases rapidly as the input voltage gets close to the point at which the switch turns off. This means they are unlikely to be useful for high-quality signal processing unless the signal amplitude is low and biased well away from the signal-induced switch-off voltage. However, single-transistor switches can be used to switch logic signals if the logic level is restored after the switch using a suitable gate.

Switches based on CMOS transmission gates show much less variation in resistance because at the input voltage at which one transistor's resistance is largest the other transistor exhibits its lowest resistance. Therefore the parallel combination can be arranged to be reasonably constant.

Resistance simulation

The simulation in Fig.5 can be modified to give an idea of resistance variation. The resistors are replaced with constant current sources to ensure some current is flowing, whatever the input voltage, and the switches are bypassed by resistors which are around a couple of orders of magnitude larger than R_{ON}, to give the current somewhere to go when the switch is off (otherwise you may get ridiculously high voltages in the simulation). The input voltage source is set to be the source of DC sweep simulation and the resistance is plotted against the swept input voltage using an expression which divides the voltage across the transistor by the current through it. For example, for the NMOS device:

```
Abs((V(inputN)-V(nmos_out))/
Id(M1))
```

The parallel resistance of one NMOS and one PMOS transistor can be plotted using an expression for parallel resistance obtained from the individual resistance expressions.

The results for the resistance simulation are show in Fig.8. This does not attempt to simulate any real device, but is sufficient to demonstrate the general behaviour of circuits of this type. The large variation in resistance for single transistor switches (upper plot) and comparatively constant, but still varying, value of parallel resistance for complementary transistors (lower plot) can be seen.

Larger transistors can be used to reduce R_{ON}, specifically it is the aspect ratio (width/length) which is important – the transistor needs to be much wider than its length to achieve low resistance (as is the case with the values shown in Fig.6). As the minimum length will be fixed for a given technology, lower resistances require relatively large transistors. However, using large transistors will increase the capacitance of the switch, which will reduce bandwidth. MOSFET R_{ON} decreases with increased gate voltage so another approach to reducing R_{ON} is to use a charge pump on the chip to generate a voltage above the supply level to control the switch transistors.

Other issues

Analogue switches have other non-ideal characteristics in addition to non-zero R_{ON} and R_{ON} variation. When the switch is open, a signal input on one side will ideally be completely blocked from reaching the other terminal – however, for real switches this is not the case and some signal will get through the switch. When a switch is closed, charge is present in the switch MOSFET channels – this is charge that happens to be flowing inside the device at that instant. The charge does not remain in the device when it is switched off, so it has to go somewhere in the external circuit – a process known as charge injection. Charge injection creates noise in the signal path. In the case of a switch connected to a sampling capacitor (as in Fig.2) the voltage level on the capacitor will shift due to the injected charge.

This article has introduced the basic circuit structure, principle of operation and some fundamental characteristics of analogue switches. Next month, we will continue to look at device characteristics, but also focus on circuit design issues when using these switches.

PIC n' Mix

Mike O'Keeffe

Our periodic column for PIC programming enlightenment

Review of PIC32 Touch Development Board

LAST MONTH, we finished the *DIY Oscilloscope* using the LPLC board. It was an interesting project, which I may revisit in the future. This month, we're going to have a look at an off-the-shelf module and its related software packages, which add power and functionality to allow us to develop incredible applications into small handheld devices. For this, I want to have a look at MikroElektronika's 'mikroC' and 'Visual TFT' software, working with their 'mikromedia for PIC32' development board.

mikromedia for PIC32

MikroElektronika has an interesting range of relatively low-cost development boards, which use a variety of microcontrollers – from ST MikroElektronika's STM32 to Atmel's XMEGA, Texas Instruments Tiva and of course our favourite range, Microchip's PIC18FJ, PIC24EP, dsPIC33EP and the PIC32.

Let's have a quick look at all the fancy features on the mikromedia for PIC32 board:

1) Full-colour touch screen (320 × 240 pixels)
2) Audio module
3) Accelerometer
4) microSD card slot
5) Flash memory
6) 44 GPIO pins

As you can see, it's bursting with functionality. It can be powered by USB, or connect to a battery and away you go. Using this wealth of features, we could develop a USB or battery-powered home monitoring system, which monitors temperature on a GPIO, shows pleasing photos (stored on a microSD card) when in sleep mode, plays MP3 music files stored on the microSD card through an attached 50Ω speaker, and which changes the song when you shake it. Right there, we've got an extremely powerful device ready to hit the world of the Internet of Things (IoT) with a bang.

Then we could start adding some wireless features like Wi-Fi, GSM or GPS, which would monitor our household temperature, send it to our phone, email it to us at work or tweet it to our many followers in the twitterverse – the possibilities are endless.

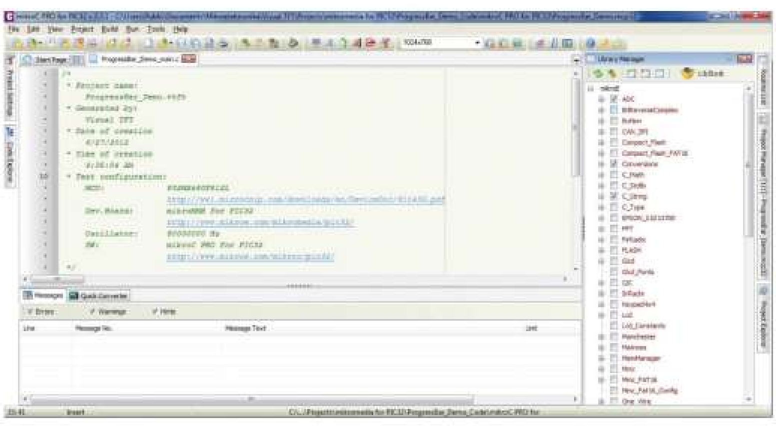


Fig.1. mikroC IDE interface

Let's take a look under the hood

MikroElektronika is based in Belgrade, Serbia. Its slogan is 'making it simple', and it aims to develop products that are easy to use and suitable for beginners. It has a wide range of development boards for PIC, dsPIC, PIC32, AVR, ARM Cortex-M, 8051, PSoC, NXP and Texas Instruments microcontrollers. This sounds ideal for hobbyists and beginners everywhere. It is also very appealing to many small companies involved in rapid prototyping.

Not only does MikroElektronika sell development boards, but it also develops software packages to help beginners get started. The two I'm looking at are 'mikroC for PIC32' and 'Visual TFT'. Now, we could develop our own software using Microchip's MPLAB X IDE, but it would take a very long time. Let's have a look at the advantages of these packages and why it is so appealing to use these over our beloved MPLAB.

mikroC for PIC32 and Libstock

mikroC is a fully-featured ANSI C compiler and IDE (integrated development environment), which comes in a few different flavours geared towards the PIC, dsPIC, PIC24 and the PIC32 series of microcontrollers. Each of these packages supports an ever-growing number of PIC devices. However, it would be unfair to say that C is the only language on offer, since you can choose to work with mikroBasic and mikroPascal instead.

Now, why would I choose another compiler and IDE over the MPLAB version? First, one of the great things that mikroC offers is Libstock. This is an included package with mikroC that comes from a community website created by MikroElectronika, that allows users to share their projects and libraries. These libraries can only be used with mikroC (or mikroBasic or mikroPascal), but it provides an easy-to-use extensive collection of ready-to-use functions. This is very useful when you don't want to write everything from scratch. You can pick from a wide range of libraries, such as: ADC, buttons, FFT, I2C, Manchester encoding, memory manager, OneWire interfaces, PS2 interfaces, PWM, SPI, TFT, UART and USB… to name but a few. It is similar to Microchip's Library for Applications (MLA) but is much larger and comes pre-installed.

Picking a random library, the OneWire library contains the functions `Ow_Reset`, `Ow_Read` and `Ow_Write`. This one library allows us to write to a single wire interface module (SWIM). These are often used in small inexpensive digital thermometers and weather instruments with low data rates and longer range. Maybe we want to play a sound instead, so lets use the sound library with the routines `Sound_Init` and `Sound_Play`. Maybe we want to do something a little more complicated, like an infinite impulse response filter (IIR) using the Q15 fractional format, we just use the IIR_Radix routine and away we go. On top of that, right click on the relevant library in the Library Manager and we can see the usage and examples of each function. Unfortunately, we can't view the actual code behind the library itself, which is a pity.

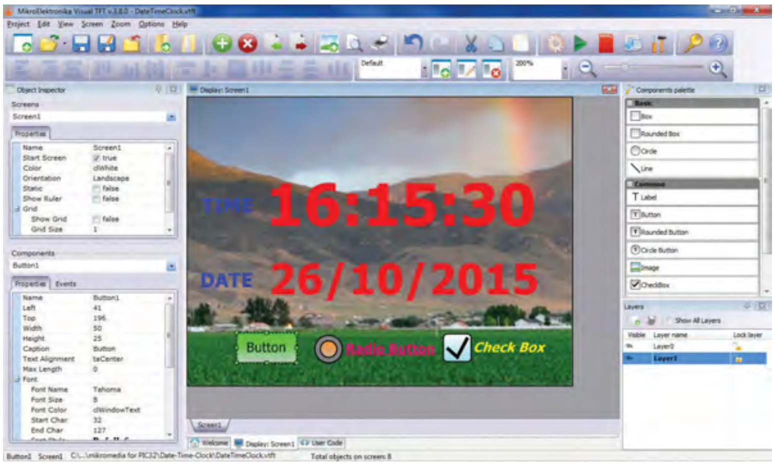


Fig.2. Visual TFT interface

Visual TFT

We've covered the physical board itself, the compiler and the IDE. What more could we possibly add to make our lives ever easier to create a really slick looking device. This is where 'Visual TFT' comes in. Visual TFT is a standalone application used for rapid development of graphical user interfaces (GUI) for TFT displays. Likewise, 'Visual GLCD' can be used for GLCD displays.

In our last project, the *DIY Oscilloscope*, we had to write each line to the screen over the SPI interface individually, which was time consuming. Imagine we wanted to draw an image – we would probably only ever be able to draw the simplest of pictures. This is where Visual TFT shines. With a simple drag and drop interface, we can place JPEG/BMP images to be displayed on the screen. We can have several screens, which we can manoeuvre through a simple touch screen press. There is a range of buttons, radio buttons, check boxes and even progress bars that we can add to our screen. In Fig.2, you can see how to alter the properties of each of these components to change the font size, colour and alignment. We can also add events to each button, so that when we press the button, it will perform a task.

This is where the real beauty of it all comes together. We've built our beautiful looking screen, so now lets get it up and working on our board. Just press the big green Play button (actually Start Compiler), and Visual TFT will not only create the necessary code, convert the image to a pixel map, but it will also open up mikroC for you to add in all the extra background functions. We're only a 'Build and Program' away from viewing it all on our TFT screen. It really is that simple. There's no need to write interfacing code. Visual TFT works seamlessly with mikroC and makes it a thoroughly enjoyable experience developing content-rich media on a small platform.

mikroProg Programmer

MikroElektronika also provides its own programmer/in-circuit debugger (ICD), which works seamlessly with mikroC and Visual TFT. The mikromedia for PIC32 comes with two programming headers. One is the standard six-pin header that works with our PICKIT3 or ICD3, which you will have to solder on yourself. The other is the mikroProg five-pin programming header, which is populated by default.

If we want to use our PICKIT3 or ICD3, we will only be able to download it to the PIC using the hex file output. mikroC can output a coff file to enable us to debug our code in MPLAB. If we want to debug using software and hardware breakpoints in real time, we'll need to use the mikroProg programmer. The programmer is a slick white box powered by USB that supports upwards of 570 PIC chipsets.

Possible inspirational projects

There are so many things we can do, using just the screen. I have seen this board used for rapid prototyping, which led to the development of a system very similar to the mikromedia for PIC32. The project used mikroC, Visual TFT and the mikroProg programmer to develop a very accurate power meter, with a GSM module. The screen would allow the customer to view power usage over the day, as well as room temperature. Another feature was the ability to setup timers for an immersion heating system.

Here's an interesting idea, if you wanted, you could develop your own mobile phone, most of the features are already there. Attach a GSM module, a lithium battery, a microphone and write up the code and we're good to go. We could call it the *PICPhone*, but I wouldn't like to try texting on it. I forgot to mention the touch screen is resistive not capacitive – most smartphones these days use capacitive touch screens, which allows much faster response and multi-touch interfaces. With a resistive touch interface, you have to physically press on the screen. This also means it's a little slower to react to your finger press and the accuracy would make it impossible for an onscreen alphabetical keyboard. We could still set up a number of screens that would allow us to dial a number and add a hang-up button that appears during the call. We could even add the ability to receive text messages.

Other interesting project possibilities include a handheld GPS locator, DPS signal generator, digital multimeter, home monitoring system, small digital photo frame, MP3 player and a remote control (with IR transceiver module).

Going back to our DIY Oscilloscope

Lets take a look back at out last article as an example, where we designed our own hardware, wired up an SPI screen interface, a few external buttons and an input pin for our *LPLC Oscilloscope*. We developed our own code, and wrote to the screen line by line as quickly as we could. With the mikromedia for PIC32, we could have done it all in less than an hour or two. With the touch screen interface, we don't need buttons any more or debounce code and we're not using up useful GPIO pins. We can add all sorts of functionality very easily and very quickly. We're no longer using an SPI interface, as it uses the Parallel Master Port (PMP) interface on the PIC instead. The parallel bus communicates with the screen much faster as well. See Fig.3 for a quick demonstration of an Oscilloscope, where we can see the voltage division of two channels, the date, an onscreen STOP button (which can change to RUN when clicked) as well as a Menu button, which opens up even more functionality for onscreen data capture.

If we want to add extra functionality, more menu options, capture more data, it's simply a matter of opening up Visual TFT, adding a new screen, drag and drop a few buttons, add some text and that's our screen laid out. Press 'Start Compile' (big green Play button) and we can add all the background code using readily available libraries from Libstock. It all comes together very quickly and really looks the part.

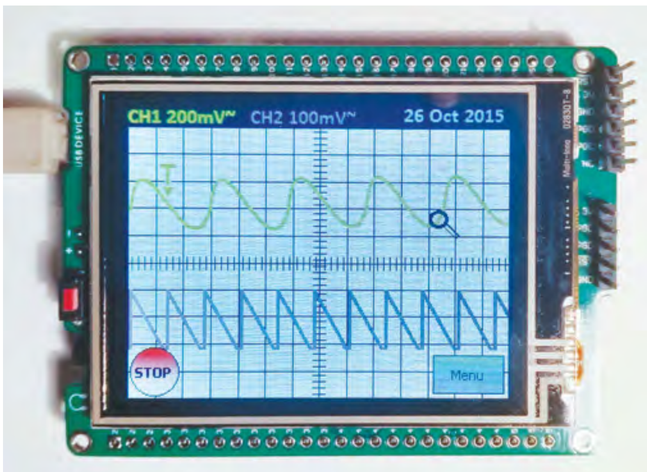


Fig.3. mikromedia for PIC32 Oscilloscope

Wrapping it all up

MikroElektronika offer a very interesting suite of products including mikroC, Visual TFT and the mikromedia for PIC32 development board. If you want to develop graphic-rich features on a small touch screen board with a few interesting options, such as an MP3 audio codec, microSD card slot and accelerometer in a short timeframe, then this is the product for you. The only downside is that it's a pity you have to learn a new IDE with all of its associated quirks, especially if you've just converted over to Microchip's MPLAB X IDE. However, in my experience, it is worth it. I enjoy building my own electronics, but there's no sense in re-inventing the wheel. With MikroElektronika's offering, we can stay focused on creating innovative and fun applications quickly and with ease.

Finally, it's worth mentioning that MikroElektronika has a great customer support team, willing to help anyone and everyone. It can be reached through their online contact form or via their online forums.

Next month

Next month, we're going to look at How to pick a PIC. I'm going to take a look at Microchips Advanced Part Selector (MAPS) and how to choose the right PIC for your project. I'm also going to delve a little into the hotly debated 8-bit versus 16-bit versus 32-bit microcontroller question. Some people question the use of 8-bit processors, when 32-bit processors offer so much more in terms of application and processing. However, each architecture has its purpose, and each has its place in the future of electronic design.

Not all of Mike's technology tinkering and discussion makes it to print. You can follow the rest of it on Twitter at *@MikePOKeeffe*, up on *EPE Chat Zone* as *mikepokeeffe* and from his blog at *mikepokeeffe.blogspot.com*

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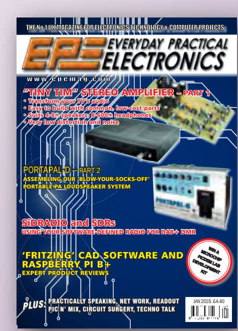

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AUDIO OUT

AUDIO OUT
L R

By Jake Rothman

Speaking volumes – Part 1

Introduction

Once an audio signal leaves the input amplifier or arrives straight from a digital source, it meets the volume control. This is the most important function in any audio system. I hear more complaints about controlling this parameter than any other, whatever method is used; touchscreen, mouse, push button, slider, or the original rotary knob. There is a somewhat childish attitude in audio that 'more is more' – louder is better – but most of the market is not interested in club-level output, and is looking for controllable ambience. A friend of mine has made a business out of combating this problem, see Fig.1. Looking at most volume control circuitry, it appears deceptively simple, but there is a whole host of electrical, mechanical and psychological interactions to be considered to get the right feel.

Fig.1. Advert showing common problem with volume controls. A simple solution is stick an attenuator on the input to expand the range of the control. However, it is definitely better to design it right in the first place!

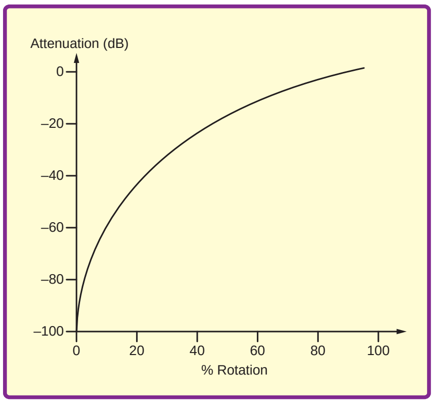

Fig.2. Ideal volume control curve

Logarithmic or linear?

All human senses are logarithmic as stated by Fechner's Law, 'subjective sensation is proportional to the logarithm of the stimulus intensity' This is why audio uses octaves and decibels, and when you upgrade your 10W amp to 100W, it only seems twice as loud. A good volume control – in theory – should have a constant decibel (dB) vs rotation curve. In practice, there are deviations to maximise the controllability, especially at the bottom part of the curve, where the attenuation needs to rapidly increase to fully cut off the signal – see Fig.2.

Simple level controls

All electronics people are familiar with the potential divider illustrated in Fig.3a. This can of course be made variable by using a potentiometer or 'pot' in audio slang. Fig3b shows the effect of a linear control, subjectively all the effect occurs in the first part of the rotation. The track has to be connected the right way round with the clockwise (CW) end at the top for

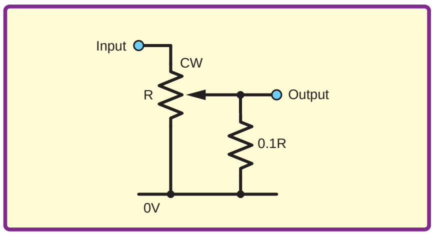

Fig.4. Loading a linear pot to obtain an approximate log law – not suitable for full range stereo controls

maximum volume. A frequent PCB error is connecting pots the wrong way, so it's essential to mark on the schematic which end of the track is which. Fig.3c shows a standard logarithmic (invariably abbreviated to 'log') control, called a '10% CW audio taper pot' in US parlance. This is because when rotated halfway

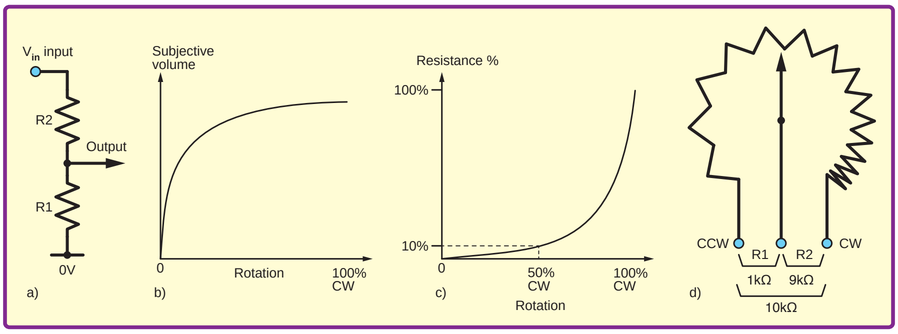

Fig.3 a) Potential divider, b) Subjective effect of linear control, c) Standard log control rate of change of resistance increases as a pot is turned clockwise, d) Measurement of log track with wiper set half-way (view is shaft towards viewer)

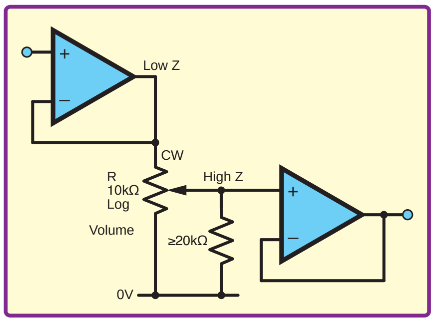

Fig.5. To ensure optimum performance, the volume control track should be fed from a low source impedance and the wiper loaded by a high impedance

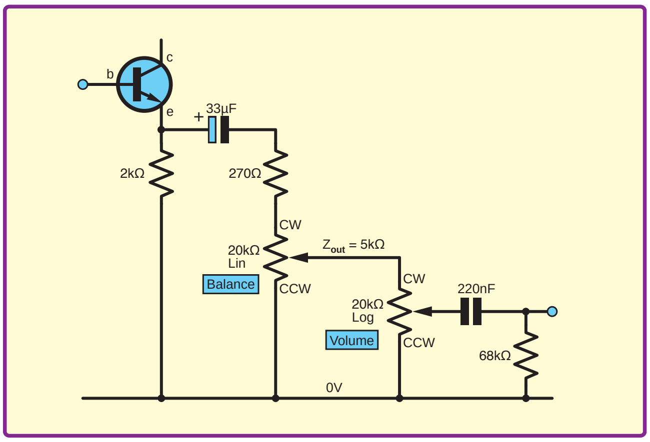

Fig.6. Leak Delta 70 circuit – the volume control is fed from the balance control, a significant source impedance, increasing volume pot errors

clockwise, the resistance will be one-tenth of the track resistance, as shown in Fig3d. If it's the other way round, it's an 'anti-log' or 'reverse-taper pot', as used in microphone pre-amp gain and frequency controls. Occasionally, 'semi-log' or '20% audio taper' pots are found, which measure one fifth of the track value. I've only seen these in oscilloscopes.

Log pots are usually marked 'A', 'lin B' and 'anti-log C'. Irritatingly, some manufacturers do the opposite to the rest of the electronics world, using 'B' to denote a 'log' pot – often the same tribe that uses a box symbol for resistors!

An inspection of any distributor's catalogue will show that nearly all high-quality pots are linear; after all, 99% of electronic control is linear.

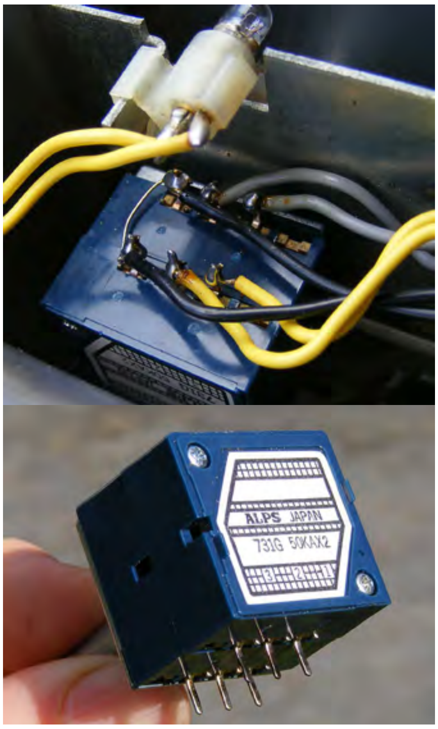

Fig.7 a) (top) Leak Delta 70 with new Alps RK2712 high tracking accuracy pot, b) (bottom) Alps RK271 pot, a six-finger wiper conductive plastic pot

As usual, audio engineers have to pay more and many circuit techniques have been developed to try and coax linear pots to give a logarithmic action. One trick popularised by Ben Duncan in the 1980s was to load a linear pot with one tenth of its track value to simulate a log pot (Fig.4). I never got it to work as a stereo control, with the sound wandering from one speaker to another in the first few degrees of rotation. Stereo mistracking is a common problem in dual-gang pots, and this technique amplifies the errors at low levels where the ear is most sensitive. It's only acceptable for limited range mono gain-trims on power amplifiers, such as the *Test Bench Amplifier* described in *EPE*, January 2015.

Installation

It's essential to feed any potentiometer from a low impedance, such as an op amp output, and load it with a high impedance of around five times the track resistance to ensure the control is ratiometric – that is, dependent only on the ratio of the resistance of the top half to the bottom half, and not the absolute track resistance. This property makes the standard stereo logarithmic volume control work much better than

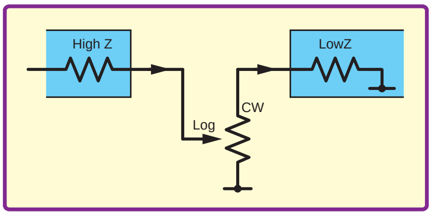

Fig.8. 'Backwards-style' current-divider volume control, used where the driving impedance is high and load impedance is low

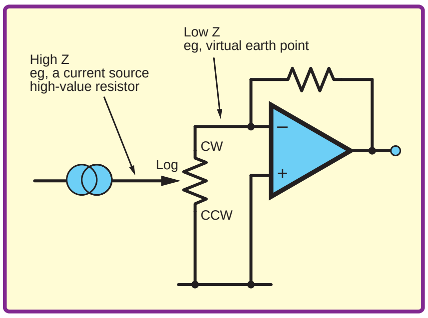

Fig.9. Current-divider volume control gives minimum noise when used on virtual earth inputs. This is because there is noise gain at minimum volume if the pot is conventionally wired

expected, despite track tolerances of up to 20% – see Fig.5. If significant source and loading impedances are introduced, errors are increased. The Leak Delta 70 discussed recently had this problem, with the balance control feeding the volume pot (Fig.6) resulting in channel imbalance. The solution is to fit a buffer stage, or in the case of my Leak, buy an expensive Alps RK271 'Blue Velvet' pot, which has high accuracy. This pot, illustrated in Fig.7, costs £7.23 from Rapid, order code 66-0225 (Farnell charge £25!).

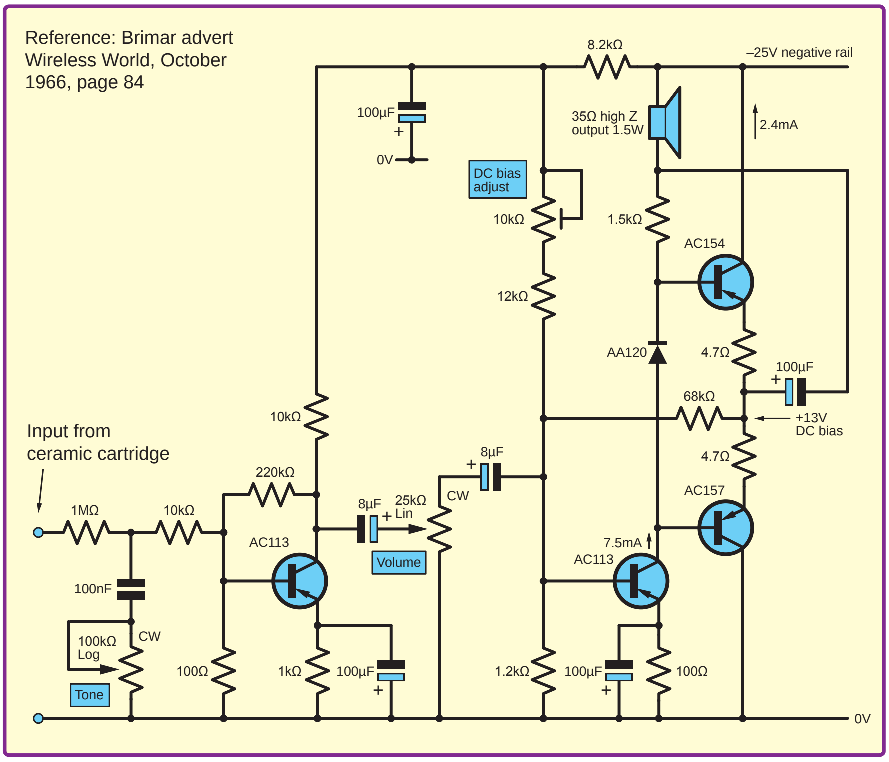

Fig.10. Old Brimar application circuit shows 'backwards' current-divider volume control

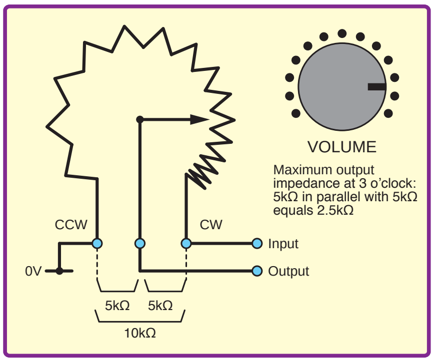

Fig.11. The maximum output impedance of a pot occurs when both top and bottom halves have the same resistance. In the case of a log volume pot it is in the 3 o'clock position

If it is intended to put a volume control between a high output impedance and a low input impedance, such as from a constant current output to a virtual earth point, then the control should be wired as shown in Fig.8, forming a current divider rather than a voltage divider. This technique maintains the log law/tracking and gives lower noise at minimum volume on inverting op amp inputs – see Fig.9. The two configurations are circuit 'duals', like star and delta connections. The current divider was often used in old low-impedance transistor circuits, such as the Brimar germanium amp in Fig.10. Interestingly, a linear pot was specified for this circuit. An almost identical Mullard circuit used a 2kΩ logarithmic pot.

It's worth pointing out here that a volume control will have a significant output impedance, which can cause treble loss if fed into a capacitive load such as long cables. The impedance is at a maximum when both top and bottom parts of the track relative to the wiper are equal value. For a 10kΩ log pot this will be 2.5kΩ at around 3 o'clock, as shown in Fig.11. The Hi-Fi craze for passive pre-amps, which are basically a pot in a box, sometimes with input switching, gives some strange effects. I met a Hi-Fi buff who said his system sounded much more 'mellow' with his new passive pre-amp. The output impedance of the 100kΩ pot used had combined with the 2.2nF RF filter capacitor on the input of his power amp to give a –3dB roll-off at 2.9kHz! A volume control in a box, like the one shown in Fig.12 is still a very useful bit of kit however, just keep the pot to 10kΩ. Musicians have these in pedal form called Swell pedals (Fig.13). These often have special pots that have short tracks, as in the Colorsound design. The log action in this case is achieved by the mechanical coupling, as shown in Fig.14.

Fig.12 a) (top) Passive pre-amp – an oxymoron describing a stereo volume pot in a box, b) (bottom) Internals of passive pre-amp – note the classic Bourns 81 pot

Coupling

Pots generally have to be AC coupled, since any DC will be modulated by the track roughness as the pot is turned, making noise. This is typically 1-2mV per volt applied across the track at a speed of one full rotation per a second. This is why old radio volume controls often crackle, because the DC load for the detector diode is the track resistance. It's much better to give the diode its own load resistor and AC couple the pot, as shown in Fig.15. The pot has to be over four times the value of the load resistor to avoid an increase in distortion.

Value

To obtain the lowest noise, it's best to use the lowest pot value one can use without loading the source. Guitar pickups and ceramic cartridges will often need 220kΩ to 1MΩ. For normal op amp circuitry, 10kΩ seems to be standard. With top-notch op amps with high current capability, lower values down to 1kΩ may be used for minimum noise. I once designed a whole mixing desk to use 10kΩ lin pots throughout. (I got a fantastic quantity discount!) With most Hi-Fi systems, a line input impedance of 47kΩ seems to be standard, mainly to allow for weak

Fig.13. Swell pedal – a volume pot in a box actuated by a pedal

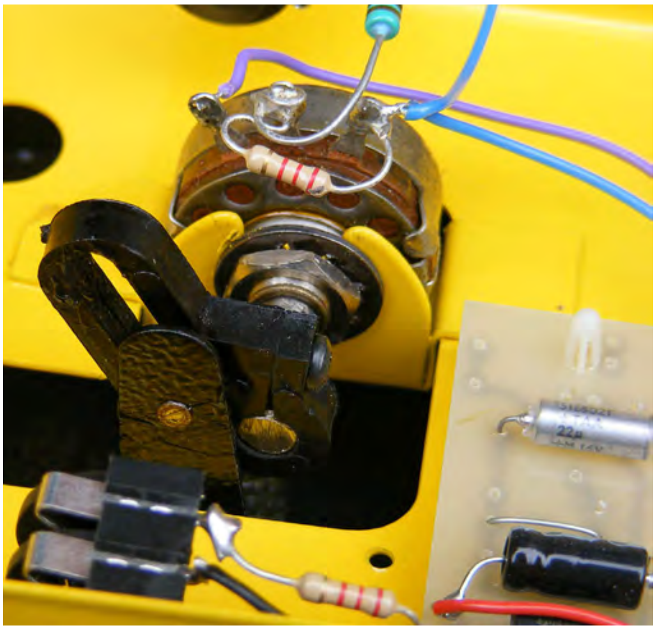

Fig.14. Mechanical linkage in Colorsound Swell pedal gives log action with short linear pot track

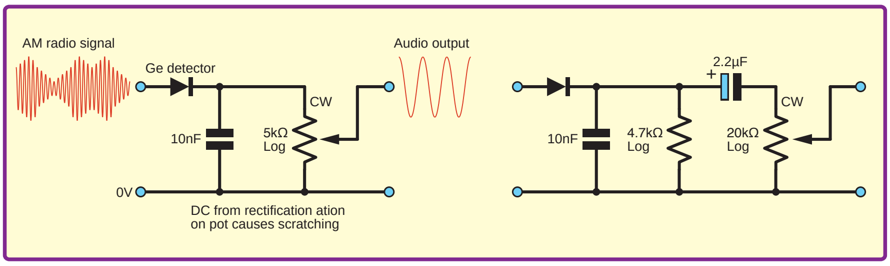

Fig.15. One cause of volume control crackling in old radios is DC on the pot track – the pot should be AC coupled

Fig.17. Earth the metal cases of pots using pot tag to avoid noise pick-up

output stages in various sources that may be connected. However, for most modern soundcards, 10kΩ will not cause appreciable loading. Generally, with the normal potential divider type volume control, the value is not very critical. It is fine to replace pots one E6 step away from their stated value. So a 47kΩ pot could be replaced with 22kΩ or 100kΩ without risking problems. Note that pots using the old value system were often used – eg, 25kΩ and 50kΩ.

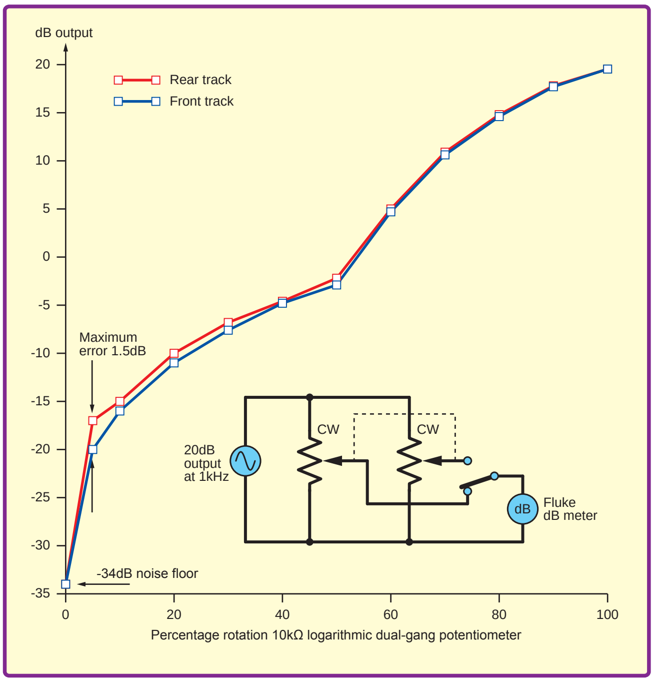

Fig.16. Typical logarithmic dual-gang pot matching curves – absolutely appalling!

Dual-gang potentiometers

Most stereo systems use dual-gang pots, one end for left, the other for right. The main problem with dual-gang pots is mismatching between the tracks, such as the curve shown in Fig.16. Like crossover distortion in power-amps, this issue has been exercising the minds of audio engineers for decades.

Earthing

There is the possibility of capacitive crosstalk in stereo pots and most metal-cased (and some plastic) units have a metal barrier between the two sections. Note that it's essential to earth all metal-cased pots. If this can't be done with a metal panel, then the case will have to be earthed by other means. Pot manufacturer Bourns make a tag specifically for this purpose, part no H-127, shown in Fig.17. The electric guitar maker approach of soldering a wire onto the case is sometimes done, but it is not recommended. With plastic-cased pots the noise pick-up can be minimised by using low values and impedances.

Next month, we'll talk about pot construction and ways round the defects of this ancient, but ergonomically superior technology.

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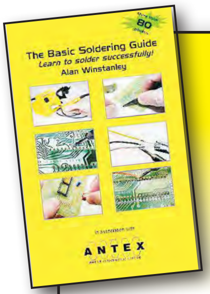

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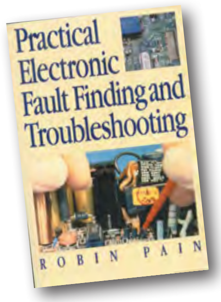

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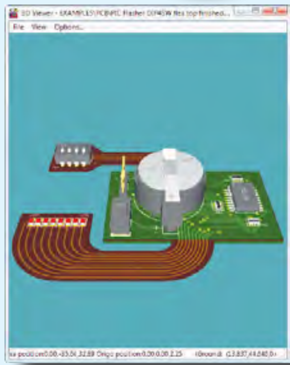

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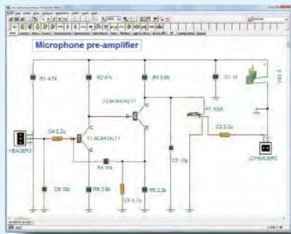

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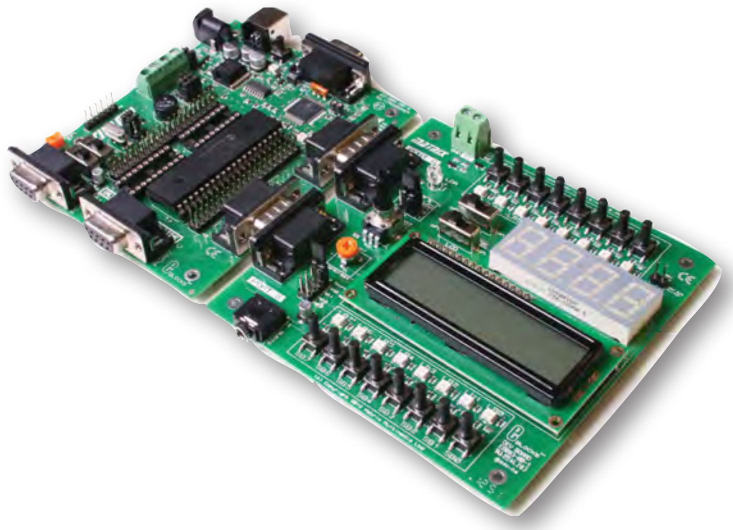

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(Formerly PICtutor)

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The CD makes use of the latest simulation techniques which provide a superb tool for learning: the Virtual PICmicro microcontroller, this is a simulation tool that allows users to write and execute MPASM assembler code for the PIC16F84 microcontroller on-screen. Using this you can actually see what happens inside the PICmicro MCU as each instruction is executed, which enhances understanding.

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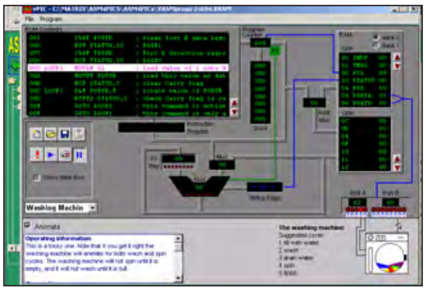

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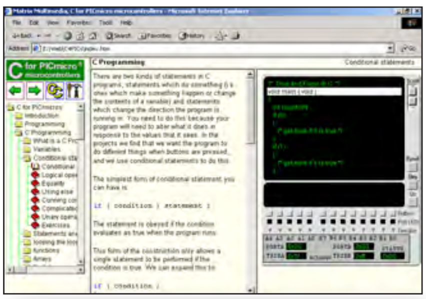

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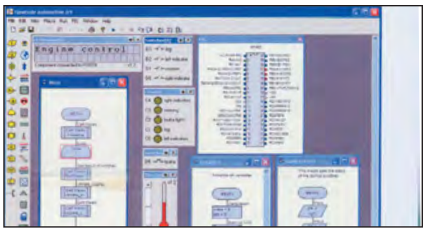

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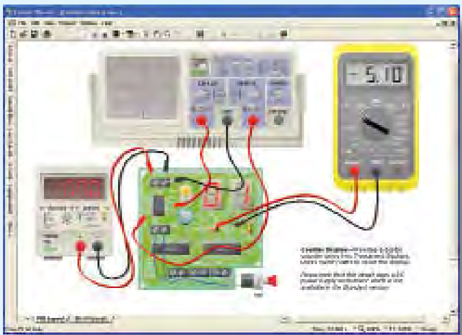

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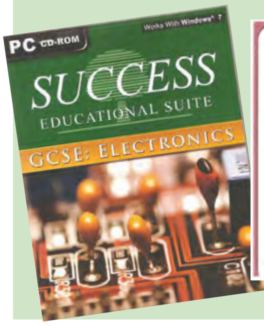

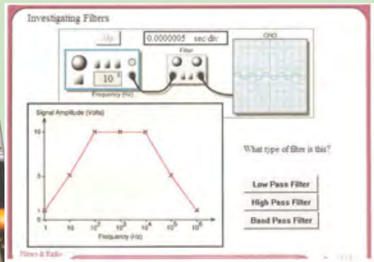

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Max's Hot Beans

By Max The Magnificent

mCookie Monster

In my previous *Hot Beans* column (*EPE*, September 2015), I presented some magnetically coupled electronic modules called 'littleBits' (**http://bit.ly/18jMIpp**). They are perfect for introducing young kids to electronics; but what about more experienced users? Well, a new range of Arduino-compatible modules called 'mCookie' might be just the answer.

First, are you familiar with the Microduino (**http://bit.ly/1JvPO6x**)? This little beauty, which is compatible with the Arduino Uno, is around 25mm × 25mm and costs about a fiver. Like the Arduino, the Microduino core (base) module is accompanied by a vast collection of stackable shield modules that can be used to implement almost any project you can imagine.

The Microduino ecosystem evolved out of two very successful crowd-funded Kickstarter campaigns. So successful, the folks at Microduino have shipped their modules to tens of thousands of users on six continents.

Following a third successful Kickstarter campaign, they have just released a new set of modules – mCookies (**http://bit.ly/1JJQVmN**). Like Microduino modules, these are small, powerful, Arduino-compatible modules for makers, designers, engineers, students, and curious tinkerers of all ages.

Anyone who has used an Arduino has learned to his or her cost that it's really easy to bend the pins when you are stacking shields together. Also, it's a lot easier to connect the shields than it is to take them apart again. In order to address these problems, mCookie modules are equipped with spring (pogo) pins that provide rugged surface-to-surface connections between the modules. Furthermore, each mCookie module has four extremely powerful magnets inside the corners, which allow them to be connected together with a satisfying snap. The modules will reject each other if they are not oriented/aligned correctly, so you simply can't get it wrong.

One feature I really like is the raised circular fixings located on each side of the module. Do these remind you of anything? Yes! You've got it! These allow mCookie modules to be stacked with LEGO-series products, thereby making it easier than ever for beginners and children to get started with DIY electronics.

Fig.1. Although tiny, mCookie modules pack a punch

Simblee delightful, my dear

Another clever product that's been around for a while now is the RFduino (**http://bit.ly/1y3e9Ro**). This is a finger-tip-sized, Arduino-compatible, wireless-enabled microcontroller, that's affordable enough to leave in all of your projects!

Fig.2. RFduino module (approx. 22mm × 28mm)

One reason the RFduino is of interest to us here is its associated ecosystem of stackable shields (I'll explain why in just a moment). Another reason is that the creators of the RFduino have launched a revolutionary new product called the Simblee (**http://bit.ly/1igMfKH**), which is tiny, measuring just 7mm × 10mm × 2.2mm.

It boasts a 32-bit ARM Cortex-M0 processor coupled with Bluetooth Low Energy (BLE) capability. Although tiny, it provides 29 general-purpose input-outputs (GPIOs), including six analogue inputs, four PWM outputs, two SPI master/slaves, two I2C connections and a UART.

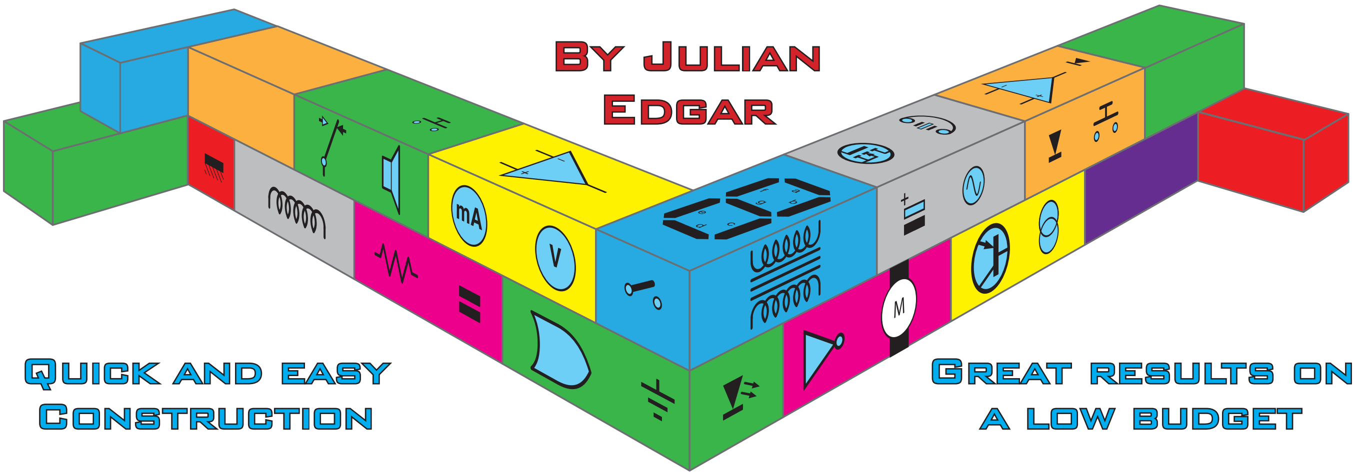
The really clever part of all this is that you use the Arduino IDE to create both your application and your graphical user interface (GUI), both of which you upload into your Simblee module. 'But why would you load the GUI into the Simblee module?', I hear you cry. Well, this is the truly clever part. There's also a free Simblee app that you can download onto any iOS or Android BLE-enabled phone or tablet computer. When you launch this app – which I tend to think of as being a 'Simblee Browser' – it automatically detects any Simblee modules in the vicinity. The app then provides you with a list of these modules and a description of each one's function. When you select a particular Simblee module, that module uploads its GUI to your phone or tablet. Pretty cool eh?

As you can see from Fig.3, these Simblee modules are small enough that you could embed them just about anywhere. I'm planning on embedding them in all of my hobby projects. But what if you aren't comfortable soldering this surface-mount module? Well, they've also provided a breakout board with an RFduino footprint, which means your Simblee module can take full advantage of the existing RFduino ecosystem. As I pen these words, I have a Simblee development kit winging its way to me. Once I've had a chance to play with it, I will report further in a future column. Until then, have a good one!

Fig.3. The tiny Simblee module (7mm × 10mm × 2.2mm)

Any comments or questions? – please feel free to send me an email at: **max@CliveMaxfield.com**

Electronic Building Blocks



By Julian Edgar

Quick and easy construction

Great results on a low budget

Electronic stethoscope for machinery

Large complex projects are fun, but they take time and can be expensive. Sometimes you just want a quick result at low cost. That's where this series of *Electronic Building Blocks* fits in. We use 'cheap as chips' components bought online to get you where you want to be... FAST! These projects range from around £15 to under a fiver... bargains!

Electronic Stethoscope for machinery

Here is a really neat device that will allow you to listen to all sorts of strange noises in machines and other devices – helping you to diagnose mechanical ills. It will cost you less than £4 for the main part of the device – just add some headphones and shielded cable.

The *Electronic Stethoscope* is based around the 'Listen Up' portable sound amplifier available from many eBay suppliers. The device is designed for people who are hard of hearing but don't want to wear a hearing aid. It comprises a small amplifier with a built-in microphone, and pair of earphones.

Fig.1. The 'Listen Up' unit

The basic unit

As supplied (Fig.1), the device is not particularly high quality and doesn't even work very well in its intended function. However, if you remote-mount the microphone and plug some decent headphones into the jack then it works rather well!

The first step is to buy 'Listen Up', some cable (I used shielded two-core microphone cable) and a 10A battery clip (you could cut a clip off any old battery charger – that's what I did).

Open the unit's box by first taking off the end caps (one covers the battery – a single AAA cell) to reveal four small screws. Undo the screws and you can open the box – see Fig.2.

Microphone

Note the microphone (arrowed). It is both a large and relatively good quality unit, and it's attached to the printed circuit board with flying leads. Unsolder the microphone leads from the board and then solder to the board the conductors of the new, shielded microphone cable, as shown in Fig.3.

I also soldered the braid of the cable to the negative connection of the battery (arrowed), to provide better shielding of the signal. Make a suitable hole for the cable to 'escape' and then close the box.

Now solder the conductors at the other end of the microphone cable to the microphone, as shown in Fig.4, keeping the cable polarity the same as the original. I chose a 4m length of

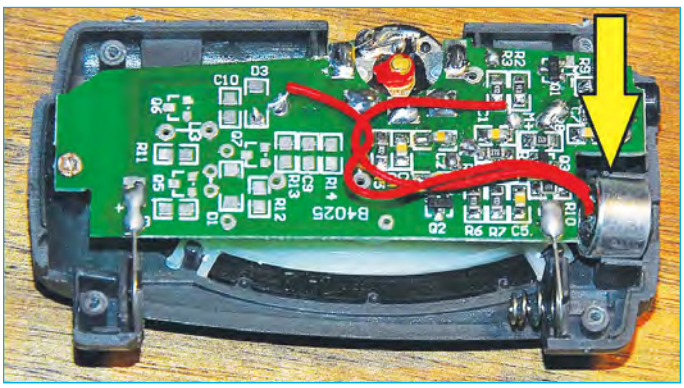


Fig.2. Locating the microphone

Fig.3. Changing the microphone wiring at the circuit board

Fig.4. Extending the microphone wiring

cable because I wanted to be able to monitor car engine noises from inside the cabin.

Next, use hot melt glue to mount the microphone on the inside arm of a metal battery clip, then cover it in heatshrink (see Fig.5). If you prefer, you could glue the microphone to the end of a steel rod. Placing the other end of the rod against the machinery will work well if you want to accurately pinpoint where a particular noise is coming from.

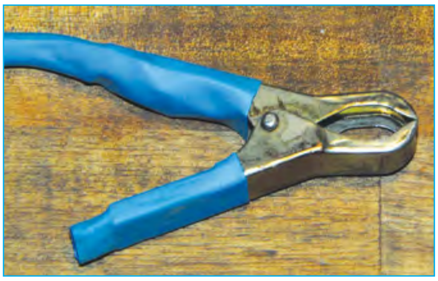


Fig.5. Mount the mic in a strong battery clip

Completed stethoscope

I mentioned that the earphones supplied with the 'Listen Up' device are pretty poor, so I recommend you supply your own. High quality, fully enclosed headphones will work best – but any decent quality earphones should also be fine. With fully enclosed headphones, the sound quality is excellent.

In use...

Using the *Electronic Stethoscope* is very simple. You simply clip the microphone to whatever you are interested in listening to. Noises are transmitted through the metalwork directly to the clip and microphone, making the device extremely sensitive.

Other fun uses

There are other uses for the modified 'Listen Up' device described here. My son, age 10, was entranced by the fact that he could use a long cable for the microphone and eavesdrop on his parents. (He also talked about taking it to school and bugging the staff room. I sometimes wonder where he gets these ideas from?!)

Given that the project involves some simple disassembly and soldering, it is electronically quite educational, so I bought him one for his birthday.

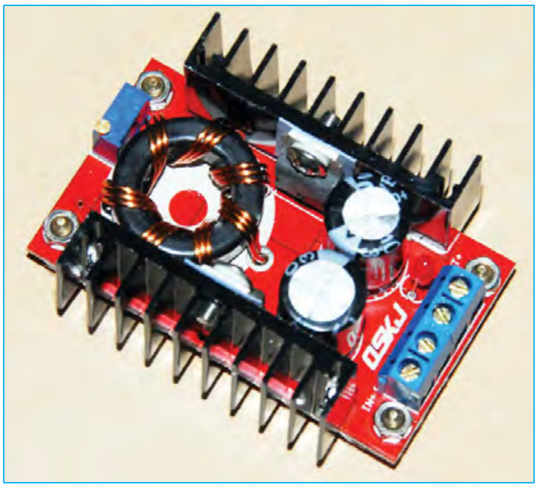
Sourcing

At the time of writing, a typical online unit is eBay item 331423381933 at a very reasonable £3.29 incl delivery.

Fig.6. The finished stethoscope

Next month

Here is an incredibly cheap voltage booster (just £5 including delivery to your UK letterbox) that has an adjustable voltage output from 12V to 35V and a decent power rating. All this is in our next *Electronic Building Blocks* article.



Next month – a voltage booster

PCB SERVICE

CHECK US OUT ON THE WEB

Basic printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are drilled and roller tinned, but all holes are a standard size. They are not silk-screened, nor do they have solder resist. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. **NOTE: PCBs from the July 2013 issue with eight digit codes** have silk screen overlays and, where applicable, are double-sided, plated through-hole, with solder masks, they are similar to the photos in the relevent project articles.

All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail.

Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

PROJECT TITLE	ORDER CODE	COST
AUG '14		
Active RF Detector Probe For DMMs	04107131	£8.02
Infrared To UHF Converter	15107131	£5.86
UHF To Infrared Converter	15107132	£9.64
Revised 10-Channel Remote Control Receiver	15106133	£16.66
PCBirdies	08104131	£9.64
USB Port Voltage Checker	24107131	£5.86
iPod Charger Adaptor	14108131	£5.86
SEPT '14		
Build An AM Radio	06101121	£9.10
LED Ladybird	08103131	£6.94
Lifesaver For Lithium or SLA Batteries	11108131	£5.32
Do Not Disturb Phone Timer	12104131	£9.10
OCT '14		
SiDRADIO – Main PCB	06109131	£24.75
– Front & Rear Panel Set	06109132 06109133	£19.35
Hi-Fi Stereo Headphone Amplifier – Part 1	01309111	£16.65
NOV '14		
GPS Tracker	05112131	£13.15
DEC '14		
PortaPAL-D – Main PCB – Microphone Input – Guitar Input	01111131 01111132 01111133	£33.94
Electronic Bellbird	08112131	£11.53
JAN '15		
"Tiny Tim" Stereo Amplifier	01309111	£16.65
– Power supply	18110131	£11.80
FEB '15		
Audio Delay For PA Systems	01110131	£13.42
Teach-In 2015 – Part 1 Pre-Amp	905	£9.33
MARCH '15		
Stereo Echo & Reverb Unit	01110131	£13.42
Super Smooth, Full-range, 10A/230V Speed Controller for Universal Motors	10102141	£11.80
APRIL '15		
A Rubidium Frequency Standard For A Song	04105141	£8.02
USB/RS-232C Interface	07103141	£7.48
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MAY '15		
Deluxe Fan Speed Controller	10104141	£10.72
RGB LED Strip Driver	16105141	£8.56
Low-cost Precision 10V DC Reference For Checking DMMs	04104141	£7.48
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Burp Charge Your Batteries	14103141	£13.40
Teach-In 2015 – Part 5	907	£8.55
JULY '15		
L-o-o-o-n-g Gating Times For The 12-Digit High-Resolution Counter	04106141	£11.55
Threshold Voltage Switch	99106141	£10.15
Touch-Screen Digital Audio Recorder – Part 2	01105141	£13.70

PROJECT TITLE	ORDER CODE	COST
AUG '15		
Nirvana Valve Simulator – Main PCB	01106141	£15.05
– Front Panel	01106142	£8.30
TempMasterMK3	21108141	£12.00
Teach-In 2015 – Part 7	908	£8.75
SEPT '15		
Opto-Theremin – Part 1 – Main Theremin	23108141	£14.25
– Volume Control Board	23108142	£6.95
Mini-D Stereo 10W/Channel Class-D Audio Amplifier	01110141	£7.45
Wideband, Active Differential Oscilloscope Probe – Main PCB – Screening PCB	04107141 04107142	£11.80
OCT '15		
Digital Effects Processor For Guitars And Musical Instruments	01110131	£16.40
Courtesy LED Lights Delay For Cars	05109141	£8.55
Teach-In 2015 – Part 9	909	£10.70
NOV '15		
The Currawong – Part 1 – Main Board	01111141	£47.20
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48V Dual Phantom Power Supply	18112141	£9.37
Programmable Mains Timer With Remote Switching – Main Board	19112141	£11.80
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*** See NOTE left regarding PCBs with eight digit codes ***

Please check price and availability in the latest issue.
A large number of older boards are listed on, and can be ordered from, our website.

Boards can only be supplied on a payment with order basis.

EPE SOFTWARE

Where available, software programs for *EPE* Projects can be downloaded free from the Library on our website, accessible via our home page at: **www.epemag.com**

PCB MASTERS

PCB masters for boards published from the March '06 issue onwards are available in PDF format free to subscribers – email **fay.kearn@wimborne.co.uk** stating which masters you would like.

EPE PRINTED CIRCUIT BOARD SERVICE

Order Code **Project** **Quantity** **Price**

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For editorial address and phone numbers see page 7

Next Month

Content may be subject to change

High-Energy Multi-Spark CDI for Performance Cars – Part 1

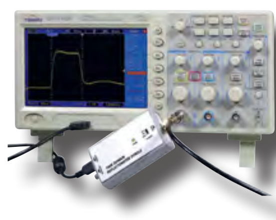
This capacitor discharge ignition system is designed to provide a very-high-energy multi-spark discharge each time the spark plug is fired. It enables complete mixture combustion in virtually all internal combustion engines used in cars and motorcycles, and is especially effective with engines that run at high RPM.

The Currawong – 2 × 10W Stereo Valve Amplifier – Part 2

In Part 1, we described the circuit and presentation of our new *Currawong Stereo Valve Amplifier*. We now describe the PCB assembly and detail the timber plinth and chassis wiring along with detailed instructions on putting it all together.

TDR Dongle For Oscilloscopes

How would you like to be able to track down faults in coaxial and other cables using time-domain reflectometry or 'TDR'? If you have a reasonably fast oscilloscope (20MHz or more), this low-cost TDR Dongle will let you do a lot of basic cable fault finding very easily.



Dremel 3D Idea Builder Printer review

3D printing is revolutionising all aspects of engineering, including the hobby construction world, and in December's issue our *Net Work* columnist Alan Winstanley gets to grips with this fascinating and important technology.

DECEMBER '15 ISSUE ON SALE 5 NOVEMBER 2015

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